Regional Monitoring Program For The Galveston Bay Plan

Galveston Bay
National Estuary Program

GBNEP-45
November 1994

Regional Monitoring Program
for
The Galveston Bay Plan

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The Galveston Bay National Estuary Program

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The Galveston Bay National Estuary Program

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The Galveston Bay National Estuary Program

Texans increasingly express their expectations for a clean environment in terms of entire ecosystems. Until recently, our tendency was to view environmental problems in isolated pieces we could understand—indeed this view was institutionalized in an elaborate mosaic of fragmented jurisdictions. The Galveston Bay National Estuary Program (GBNEP) is a forerunner in elevating hands-on management of coastal environments to the level of the ecosystem; and in doing so, is encouraging an integration of traditionally disparate institutions.

The GBNEP was established under the authority of the Water Quality Act of 1987 to develop a *Comprehensive Conservation and Management Plan* (CCMP) for Galveston Bay. The CCMP for Galveston Bay is titled *The Galveston Bay Plan*. The purpose of *The Galveston Bay Plan* is to address threats to the Bay resulting from pollution, development, and overuse. To address these threats, five years of work commenced in 1990, consisting of three phases: (1) identification of the specific problems facing the Bay; (2) a Bay-wide effort to compile data and information to describe status, trends, and probable causes related to the identified problems; and (3) creation of the CCMP itself to enhance governance of the Bay at the ecosystem level. The GBNEP is accomplishing this work through a cooperative agreement between the U.S. Environmental Protection Agency (Region 6) and the State of Texas (administered by the Texas Natural Resource Conservation Commission).

The structure of the GBNEP reflects a strong commitment to consensus-building among all Galveston Bay user groups, government agencies, and the public. The GBNEP "Management Conference" consists of six Governor-appointed committees with broad representation. Meetings of these committees are open to the public, and public participation in policy-setting and in bay management are considered strengths of the program. When submitted to the Governor of Texas in late 1994, the CCMP will reflect thousands of hours of involvement (much in the form of volunteer time) by those who use, enjoy, or help govern the vital resources of Galveston Bay.

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Glossary of Acronyms

BMP	Best Management Plan
BOD	Biological Oxygen Demand
CBOD	Carbonaceous Biological; Oxygen Demand
C-CAP	Coast Watch Change Analysis Program (NOAA)
CCMP	Comprehensive Conservation and Management Plan
CMP	Coastal Management Plan
COC	Contaminant of Concern
DIMS	Data information Management System
DO	Dissolved Oxygen
DPW&E	City of Houston - Department of Public Works and Engineering
EMAP-E	Environmental Monitoring and Assessment Program - Estuaries
FC	Fecal Coliform
GIS	Geographic Information System
GBNEP	Galveston Bay National Estuary Program
GBRMP	Galveston Bay Regional Monitoring Program
GCHD	Galveston County Health District
GLO	Texas General Land Office
HCPCD	Harris County Pollution Control Department
H-GAC	Houston- Galveston Area Council
HSC	Houston Ship Channel
NAWDEX	
NEP	National Estuary Program
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Non-point Source
NSSP	National Shellfish Sanitation Program
PAH	Poly Aromatic Hydrocarbons
PCB	Poly chlorinated Biphenyl
POTW	Publicly Owned Treatment Works
QA/QC	Quality Assurance and Quality Control
R-EMAP	Regional- Environmental Monitoring and Assessment Program
SWCB	Texas Soil & Water Conservation Board
TCWC	Texas Colonial Waterbird Census
TDH	Texas Department of Health
TMDL	Total Maximum Daily Load
TNRCC	Texas Natural Resource Conservation Commission
TNRIS	Texas Natural Resources Information Service
TOC	Total Organic Carbon
TPWD	Texas Parks and Wildlife Department
TSS	Total Suspended Solids
TWC	Texas Water Commission (now the TNRCC)

TWDB	Texas Water Development Board
USCE	United States Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
WVA	Wetland Value Assessment Methodology

Executive Summary

The Galveston Bay National Estuary Program (GBNEP) was established under the Water Quality Act of 1987 to develop a Comprehensive Conservation Management Plan (CCMP) for Galveston Bay. In 1990 work began to: (1) identify specific problems facing the Bay, (2) compile bay-wide data and information to describe the status, trends, and probable causes related to the identified problems, and (3) create a comprehensive plan to enhance governance of the bay at the ecosystem level. Based on five years of intensive work by the diverse members of an appointed "Management Conference", *The Galveston Bay Plan* was created in 1994 for submission to the Governor of Texas and Administrator of EPA.

National Estuary Program guidance requires the development of a detailed Environmental Monitoring Plan, as a separate support document to be submitted as a supplement to *The Galveston Bay Plan*. The two major goals for monitoring work as defined in EPA guidance are: 1) to measure the effectiveness of the management plan's actions and objectives; and 2) to provide essential information that can be used to redirect and focus actions implemented under *The Plan* as they are actually carried out.

To accomplish this task, a Monitoring Work Group of technical experts was created to develop and recommend to the Management Conference a detailed regional monitoring implementation plan. This work group built on work of a previous Monitoring/Data and Information Task Force convened during Galveston Bay Plan development, and began work under the following goal statement:

> The Regional Monitoring Program will be developed as a statistically sound, holistic monitoring effort designed to provide environmental data of known quality and confidence. It will be responsive to CCMP management goals and objectives, and will also have a larger goal of providing knowledge of bay-wide ecosystems, their variability, and societal impacts both environmental and ecological. Understanding that no agency's mandate is broad enough for this undertaking, the Regional Monitoring Program is seeking to promote a cooperative effort by all agencies, organizations, and other stakeholders who participate in bay monitoring activities. The Galveston Bay Regional Monitoring Program attempts to integrate and expand the disparate monitoring efforts currently active on the Bay into a comprehensive and unified monitoring plan. The regional monitoring program will integrate current monitoring efforts to the maximum extent possible, while acceding to the independent objectives of the groups involved. The plan will be developed with full participation of all interested agencies in order to encourage cooperation, communication and to maximize the potential for successful implementation.

Based on this approach, the Monitoring Work Group began to flesh out the broad monitoring recommendations in the draft *Galveston Bay Plan*. Based on contracted work by Tetra Tech, Inc., and numerous strategy sessions, this report was drafted to meet Galveston Bay's monitoring needs and comply with the requirements for

CCMP approval by EPA. As the strategy was developed, *The Galveston Bay Plan* itself was also revised to reflect the progress of the Monitoring Work Group.

This document is intended as a supplement to Chapter VI in *The Galveston Bay Plan,* providing a technical and practical rationale for future Galveston Bay monitoring activities. The report does not attempt to provide ultimate detail for the Monitoring Program, but serves as a framework from which a comprehensive monitoring program will be implemented. An appendix to the document, Protocols for Sample Collection and Analysis: Galveston Bay Regional Monitoring Program, contains the detailed information necessary to implement the program at the field level.

The Galveston Bay Regional Monitoring Program is designed to address two types of monitoring efforts: programmatic and environmental. Programmatic monitoring provides information to address the questions: "Are the goals and objectives set forth in *The Plan* being met?" and "Are the regulatory agencies meeting their commitments to *The Plan*?" In contrast, environmental monitoring attempts to provide answers to the broader question "Is the health of the ecosystem improving?" The process and principles used in developing the monitoring program are discussed in Chapter 2: Framework for Developing the Regional Monitoring Program. Overall, regional monitoring seeks to:

- Measure the status and effectiveness of *Plan* Actions,
- Establish consistent performance criteria and develop effective quality assurance and quality control programs to promote comparability between data collection efforts,
- Characterize the status and trends of conditions in the bay,
- Integrate existing monitoring efforts to the greatest extent possible,
- Make use of ecological indicators to assess status and trends in bay resources,
- Be overseen and coordinated by a multi-agency committee which will advise the Galveston Bay Program of the TNRCC, and
- Develop a data management strategy to ensure access to monitoring information.

The various agency partners involved in Galveston Bay monitoring each have specific mandates to meet, regardless of monitoring actions tied to *The Galveston Bay Plan.* However, in most cases, the Monitoring Work Group found that ongoing agency activities were flexible enough to serve both specific agency purposes and the broader goals of *The Plan.* In support of a commitment to utilize these ongoing monitoring efforts wherever possible, the first task was to catalogue the existing monitoring activities in the Galveston Bay System. A summary of these activities is given in Chapter 3. Subsequent chapters in this report address the monitoring program for each of four primary management topics:

Habitat/Living Resources Conservation

Chapter 4 - Habitat Condition
Chapter 5 - Species Distribution and Condition

Balanced Human Uses

Chapter 6 - Public Health
Chapter 7 - Freshwater Inflow
Chapter 8 - Spills / Dumping
Chapter 9 - Shoreline Management

Water and Sediment Quality Improvement

Chapter 10 - Water and Sediment Quality
Chapter 11 - Non-Point Sources of Pollution
Chapter 12 - Point Sources of Pollution

Data Information Management System

Chapter 13- Communicating Results: Data and Information Management

Habitat/Living Resources Conservation Chapters 4 and 5 address the monitoring requirements for providing maintenance and restoration of the critical habitats which make up the Galveston Bay Estuary ecosystem, and protection of the many species which make their home in the estuary or depend on the estuary for part of their life cycle. Chapter 4 discusses a monitoring program designed to assess the management goals and objectives for Habitat Condition. A program for assessment of the quality and quantity of vegetated wetlands is presented. Assessments of wetland status, areal extent, and distribution will be accomplished through use standardized computerized technology for classification of coastal habitats from satellite thematic mapper multi-spectral imagery. The recommended protocols are the NOAA Coast Watch Change Analysis Program. These protocols have been adopted and implemented in Texas by the Texas Parks and Wildlife Department, Resource Protection Division. Landcover inventories and change analysis information for Texas coastal areas, including Galveston Bay, will be available at 3-5 year intervals. This land cover classification data is available in GIS format and can be readily integrated into the proposed Galveston Bay Data Information System.

The second element of habitat monitoring, habitat quality, will utilize information on wetland distribution to rank wetland quality assessments. Habitat quality may be defined through the functions and values that characterize a wetland. Functions, are the ecological benefits that a habitat provides. Wetland functions include fish and wildlife habitat, nursery habitat, and food web support. Wetland values are a measure of the human benefits provided by a habitat. These include flood control, groundwater recharge, and recreational opportunities. By defining a degraded wetland habitat as one that no longer performs one or more of its function or value roles, quality assessments can be defined in terms of ability to perform these roles. For assessing wetland quality the monitoring program proposes the development of the USFWS Wetland Value Assessment technique. This technique is a community-oriented approach assessment tool which can be used to quantify changes in habitat quality. The WVA works under the premise that optimal conditions of habitat quality can be characterized and that an index of wetland quality can be developed against that optimal condition. This approach emphasizes the concept that species protection is inextricably linked to habitat protection.

To address species management problems in the Bay, Chapter 5 develops a suite of monitoring programs directed at assessing the measurement of population trends of economically and ecologically important plant and animal species. This monitoring element relies heavily on the Coastal Fisheries sampling program conducted by the Texas Parks and Wildlife Department. Specific monitoring elements address: fish and crustacean population levels; oyster populations; and the effects of pressures such as commercial by-catch, and impingement and entrainment on fish and crustacean populations. The plan also addresses the issues of monitoring for assessing reductions in populations of nuisance species and enhancing endangered and threatened species populations.

Balanced Human Uses The second primary management topic, Balanced Human Uses, addresses many of the impacts to the Bay, direct and indirect, from the human population residing in close proximity to the Bay. This topic deals with maintaining a balance between public access to bay resources and the environmental requirements of a healthy ecosystem. Four categories of human uses of the bay were developed and are summarized in the ensuing discussions of Chapters 6-9.

Chapter 6, Public Health Protection, addresses issues impacting human consumption of Bay products such as fish and shellfish and contact recreation opportunities provided by the Bay. Monitoring in this section provides information to improve assessments of the safety of oyster harvest areas, development of a risk-based seafood consumption program, and development of a Contact Recreation Advisory Program. In response to these concerns the Texas Department of Health will seek funds to expand its monitoring program for the harvest of shellfish and will develop a routine fish and crustacean tissue sampling program. This program will be designed to allow for development of risk-based program to safeguard the quality of seafood production in the Bay. These programs will be coordinated with the Galveston Bay Regional Monitoring Program.

Chapter 7 addresses the important issue of the continued flow of high quality fresh water into the estuary. A balanced salt/fresh water mix is critical for the survival of most estuarine species and is vital to maintaining biodiversity within the system. The Texas Water Development Board with the Texas Parks and Wildlife Department is currently completing a freshwater inflow-biological resources optimization model which will be used to determine the quantities and timing of freshwater needed to maintain the current abundance of biological resources. Continued monitoring of freshwater inflow quantity and timing is critical to the success of Bay management. To accomplish this monitoring objective the program will work with the U.S. Geological Survey to strengthen and improve the stream flow monitoring network in the Galveston Bay system.

Chapters 8 and 9 address the impacts of spills and dumping and of shoreline development on the Bay. The plan treats monitoring for these impacts as primarily programmatic, rather than environmental. Plans for assessing activities designed to reduce impacts to the system from spills include the tracking of: adoption of improved damage assessment procedures; bay-wide baseline data on pre-release conditions; and monitoring development of local measures to remove floating trash and debris from stormwater discharges. Tracking to assess progress in Shoreline Management actions plans will include: assessing local authorities for development of shoreline development regulations consistent with those outlined in the plan; monitoring for derelict structures and their removal; and actions directed at improving access to bay shoreline.

Water and Sediment Quality Improvement This monitoring element addresses relationships between water and sediment quality and pollutant loadings to the bay. Action plans were developed to address general water and sediment quality issues, non-point source issues and point source issues.

Monitoring of water and sediment quality emphasizes toxic substances and dissolved oxygen in certain tributaries and side bays. All monitoring activities will be made comparable through establishment of consistent performance criteria and development of effective quality assurance and quality control programs. An open-bay sampling program emphasizes the utilization of a probability-based, systematic sampling program to provide rigorous, unbiased estimates of environmental conditions in the open and tidal portions of the Bay. Monitoring in the bay watershed will be accomplished through the comparability element and coördination of efforts through local and state agencies and programs such as the Texas Clean Rivers Program.

Non-point source (NPS) runoff has been targeted as the second-most important priority problem to the bay. Chapter 11 outlines the monitoring efforts for the non-point source action plan. Plan actions to address non-point sources call for the development and implementation of Best Management Practices (BMPs) for reducing NPS loadings from existing urban development, new urban development, construction, agriculture, industry, and marinas. The major emphasis on monitoring progress toward attaining action plan objectives is reviewing the implementation and success of NPS BMPs and stormwater management plans. Most of the monitoring data to be utilized to monitor reductions in NPS loads will come from special pilot projects, NPDES stormwater permit reporting requirements (including wet weather sampling) and indirectly from other elements of the regional monitoring program.

Over the last three decades, there has been a dramatic reduction in point source loads to the bay, however there are still some areas of concern. Many municipal systems continue to bypass and have overflow and collection system problems. The primary concern being the discharge of raw or partially treated sewage to the bay. A second identified problem are the continued localized impacts of produced water discharges to aquatic life in the tidal zones of the bay. Monitoring emphasis here again emphasizes programmatic issues, such as development of dry-weather illegal connection programs and elimination of bypass and overflow problems. The monitoring of fecal coliform bacteria under other elements of the regional monitoring program will provide information to document overall reductions in fecal coliform counts in the bay system. Proposed plan action on produced water dischargers calls for the issuance of an EPA general permit which would eliminate discharges from this source. Monitoring surveys will be developed to document environmental improvements resulting from this action.

Data Information Management System An important element of the Galveston Bay Regional Monitoring Program will be the improved management of monitoring of data to enhance communication of bay trends and conditions to managers and the public. A Data Information Management System (DIMS)is to be used to house and distribute the data collected through the monitoring activities of the program.

The program recommends development of a centralized data storage system utilizing the power of Geographical Information Systems to manage and present the data in a format useful to resource managers. The plan addresses the need to ensure long-term integrity, quality, and accessibility of data. Beyond this the system addresses the need to facilitate the integration and analysis of the data and to provide statistical, graphical, spatial analysis and mapping capabilities.

Critical to the development of a comprehensive Galveston Bay DIMS is the Texas Clean Rivers Program. The Clean Rivers program complements the Galveston Bay Program by providing a coordinated assessment of river basins, within the Galveston Bay estuary, utilizing a watershed management approach. Within the Galveston Bay watershed, the Clean Rivers Program is administered by the Houston-Galveston Area Council (H-GAC). Centralization of the data information resources of the Clean Rivers Program and the Galveston Bay Program within the H-GAC is the centerpiece of the Galveston Bay DIMS. Such an arrangement will simplify the tasks of storing, maintaining, locating, querying, and retrieving regional monitoring data.

Utilizing the Geographic Information System (GIS) already in place within H-GAC, a direct electronic link will be established between the H-GAC and the Galveston Bay Program to allow access to all information within the centralized data base. Information from this system will be available from the Galveston Bay Program as raw data, technical reports for the scientific community, and non-technical summaries for the public. This data will be used to assess plan progress with environmental actions on an annual basis. Results will be distributed through the Galveston Bay Program Publications, the State of the Bay Symposium to be held every two years, and other public and scientific forums.

Chapter 1

Introduction

The Clean Water Act as amended by the Water Quality Act of 1987 establishes the National Estuary Program (NEP) to promote long term planning and management in nationally significant estuaries threatened by pollution, development, or overuse. Section 320 of the Clean Water Act describes the establishment of a management conference in each estuary to develop a Comprehensive Conservation and Management Plan (CCMP). It also establishes requirements to monitor the effectiveness of actions taken pursuant to the plan.

Galveston Bay National Estuary Program

The Galveston Bay National Estuary Program (GBNEP) was established under the authority of the Water Quality Act of 1987 to develop a CCMP for Galveston Bay. In 1990 work commenced to (1) identify specific problems facing the Bay, (2) compile bay-wide data and information to describe the status, trends, and probable causes related to the identified problems, and (3) create the CCMP document to enhance governance of the Bay at the ecosystem level. GBNEP is accomplishing this work through cooperative agreement between the US Environmental Protection Agency (USEPA) Region 6 and the State of Texas administered by the Texas Natural Resource Conservation Commission (TNRCC). The structure of GBNEP reflects a strong commitment to consensus-building among all Galveston Bay user groups, government agencies, and the public. This regional effort reflects thousand of hours of involvement by individuals who use, enjoy, or help govern this vital coastal resource.

Commitment to Monitoring

One of the early commitments of the Galveston Bay National Estuary Program was to the development of a sound regional monitoring program. The need for such a program was formalized at the Galveston Bay National Estuary Program- Regional Monitoring Conference held in Galveston, Texas on July 8-9, 1992. The conference was widely attended by technical experts and managers of local, state and federal programs administering monitoring activities in Galveston Bay. From this conference come the conceptual framework for the development of a regional monitoring program. Recommendations from this conference included the following points (Tetra Tech, 1992).

- A regional monitoring program is needed to improve our ability to effectively manage resources in the estuary,
- Establishment and management of a technically sound regional monitoring program is feasible,
- The details of the monitoring program should be designed by technical experts working with managers and decision makers.

With this guidance, the *Galveston Bay Regional Monitoring Strategy* (Tetra Tech, 1994) document was created. This document centers around describing the Task Force findings for five central management topics. These topics were identified by the GBNEP program office and are further described in the Galveston Bay Comprehensive Conservation and Management Plan (CCMP). They are:

- Water and sediment quality
- Species population protection
- Habitat protection
- Freshwater inflow
- Public health protection

A Task Force was established for each of the five management topics with meetings being held over a period of months. Each task force was charged with developing action plan items to address perceived threats and concerns. Once these action plans were incorporated into the CCMP monitoring objectives and information needs were developed. A detailed account of this process and the results of the Task Force findings are found in the *Galveston Bay Regional Monitoring Strategy* (Tetra Tech, 1994). This document served as a guidance document for development of the monitoring program but did not fulfill the requirements for a monitoring plan as defined in the CCMP approval guidance (USEPA, 1992a).

Monitoring Guidance

The primary objectives and requirements of the implementation plan are established in the *National Estuary Program Guidance: Comprehensive Conservation and Management Plans: Content and Approval Requirements* document. The goals for the monitoring plan are:

- To measure the effectiveness of the management plan action and objectives
- To provide essential information that can be used to redirect and focus the CCMP during implementation.

The specific requirements of the plan are:

- To define program objectives and performance criteria (i.e. parameters to be monitored,
- To identify testable hypotheses,

- To specify monitoring variables, including sampling locations, monitoring frequency, field and laboratory methods and QA/QC procedures,
- To specify data management system and statistical tests to analyze the monitoring data,
- To describe the expected performance of the initial sampling design, and
- To provide a timetable for analyzing data and assessing program performance.

To accomplish this task the Monitoring Work Group was created to develop a detailed implementation plan that builds on the task force recommendations and which meets the requirements for CCMP approval. This work group was constructed as an interagency assemblage of monitoring and monitoring technical experts. The following goal statement was developed to give guidance and direction to the work group.

> The Regional Monitoring Program will be developed as a statistically sound, holistic monitoring effort designed to provide environmental data of known quality and confidence. It will be responsive to CCMP management goals and objectives, but will also have a larger goal of providing knowledge of bay-wide ecosystems, their variability, and societal impacts both environmental and ecological. Understanding that no agency's mandate is broad enough for this undertaking, the Regional Monitoring Program is seeking to promote a cooperative effort by all agencies, organizations, and other stakeholders who participate in bay monitoring activities. The Galveston Bay Regional Monitoring Program attempts to integrate and expand the disparate monitoring efforts currently active on the Bay into a comprehensive and unified monitoring plan. The regional monitoring program will integrate current monitoring efforts to the maximum extent possible, while acceding to the independent objectives of the groups involved. The plan will be developed with full participation of all interested agencies in order to encourage cooperation and communication and to maximize the potential for successful implementation.

An attempt is made to provide detailed rationale, both technical and practical, for the selection of monitoring indicators. Much of the information presented is documented more completely in the *Galveston Bay Regional Monitoring Strategy* (Tetra Tech, 1994a). The second of two Tetra Tech documents, *Protocols for Sample Collection and Analysis: Galveston Bay Regional Monitoring Program* (Tetra Tech, 1994b), included as Appendix A of this document, is a monitoring protocol standardization document. Information from both documents, has been utilized in creating the final *Galveston Bay Regional Monitoring Program* document.

Also critical in the creation of this document were the members of the GBNEP Regional Monitoring Work Group. Through their combined efforts this monitoring plan has evolved from a group of broad suggestions and guidelines to a functional and implementable plan. Special thanks are extended to Work Group members George Guillen (Texas Natural Resources Conservation Commission), Kirk Wiles (Texas Department of Health), Lance Robinson (Texas Parks and Wildlife

Department), Dr. Norris Tyer, Jr. (Harris County Pollution Control Department), Gary Fogarty (Galveston County Health District), Theo Glanton (City of Houston-Department of Public Works and Engineering), Terry Fisher (City of Houston-Environmental Health Division), Frederick Werner (U.S. Fish and Wildlife Service), Dr. Fred Liscum (U.S. Geological Survey), Carl Masterson (Houston-Galveston Area Council), and the many others who participated in the many focus groups.

Chapter 2

Framework For Developing The Regional Monitoring Program

Overview

Monitoring means different things to different people:

> *"The continued systematic time-series observation of predetermined pollutants or pertinent components of the ecosystem over a period of time sufficient to determine 1) the existing levels, 2) trends, and 3) natural variations of measured components."*
>
> (National Oceanic and Atmospheric Administration, 1979)

> *"To watch, observe, or check, especially for a special purpose."*
>
> (Webster's)

The Regional Monitoring Plan is designed to answer two different types of questions about Galveston Bay. The first type of question asks "are the goals and objectives set forth in *The Galveston Bay Plan* being met?" Are the regulatory agencies and the regulated community fulfilling their commitments to *The Plan*? Are actions in *The Plan* having the desired impact? Does *The Plan* need to be changed? If the monitoring results indicate that the plan objectives are not being met, then the actions can be modified or the objectives can be changed to reflect a better scientific understanding about the bay.

The second type of question, which is much broader, asks "is the health of the ecosystem changing , either for the better or the worse?" To answer this type of question, information from the monitoring program may be used to:

- Improve our understanding of Bay systems,
- Assist in setting environmental standards, and
- Support the development of predictive tools

Two distinct monitoring elements are needed to provide the information to answer these questions. These monitoring elements, programmatic and environmental, each provide information needed to evaluate *The Plan* at various levels. There are three identifiable levels at which we will use monitoring information to assess plan progress. These levels are administrative, symptomatic, and ecosystem (Figure 2-1). Administrative monitoring, essentially a tracking function, establishes accountability of designated lead agencies for carrying out specific actions outlined in the plan. It is often desirable to measure non-environmental outcomes such as changes in opinion, knowledge or behavior concerning a specific plan action. This we are defining as programmatic monitoring conducted at a symptomatic level. The term symptomatic monitoring is used to define the center of the monitoring spectrum which includes both programmatic monitoring which is beyond simple administrative action and monitoring of primary environmental stress indicators. An example of symptomatic level monitoring would be a survey to determine if an educational outreach program has had the desired effect on the target community. For example in The Plan, Action NPS-15 restricts the use of marine sanitary chemicals. A survey of boat owners could be undertaken to evaluate the level of compliance with this action.

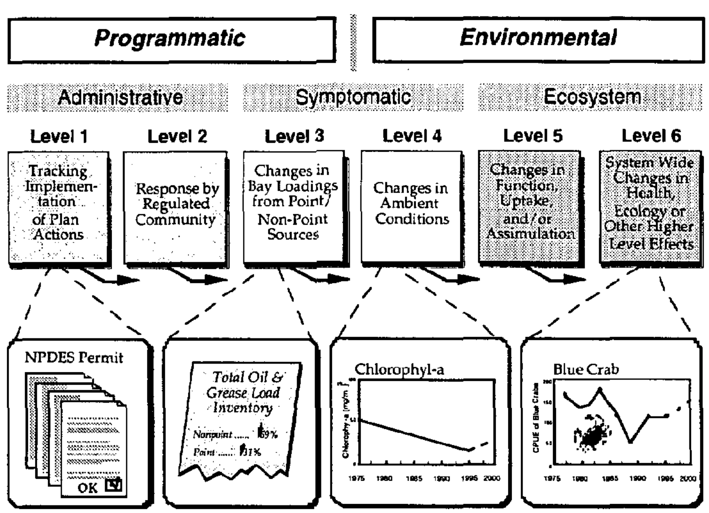

Figure 2-1. Monitoring Hierarchy in the Galveston Bay Regional Monitoring Plan.

Environmental monitoring can also be thought of in terms of levels of information. While it can be argued that environmental monitoring evaluates outcomes, there are two different levels at which we can conduct environmental monitoring. At one level we measure certain parameters, stress indicators, as a measure of whether plan actions are having an observable environmental impact. We are classifying this level of environmental monitoring as symptomatic in the monitoring continuum shown in Figure 2-1. Symptomatic environmental monitoring includes such things as reductions in point or non-point loadings, changes in ambient nutrient concentration trends, or changes in bird nesting habitat. While these indicators may be symptomatic of qualities we deem necessary for a healthy ecosystem, they do not directly measure ecosystem health. Such higher level indicators, often called response indicators, are measured as reduced human health risk from bay fish and shellfish consumption, changes in primary productivity, or increases in reproductive success in nesting bird populations. This hierarchy of indicators, shown in Figure 2-1 has been modified from the Chesapeake Bay program. To demonstrate how each component of *The Plan* fits into this hierarchy Figure 2-2 shows how, when we integrate the levels of monitoring with the implementation strategies, we can see that all Plan actions contribute to the common goal of restoring the ecosystem to optimal health.

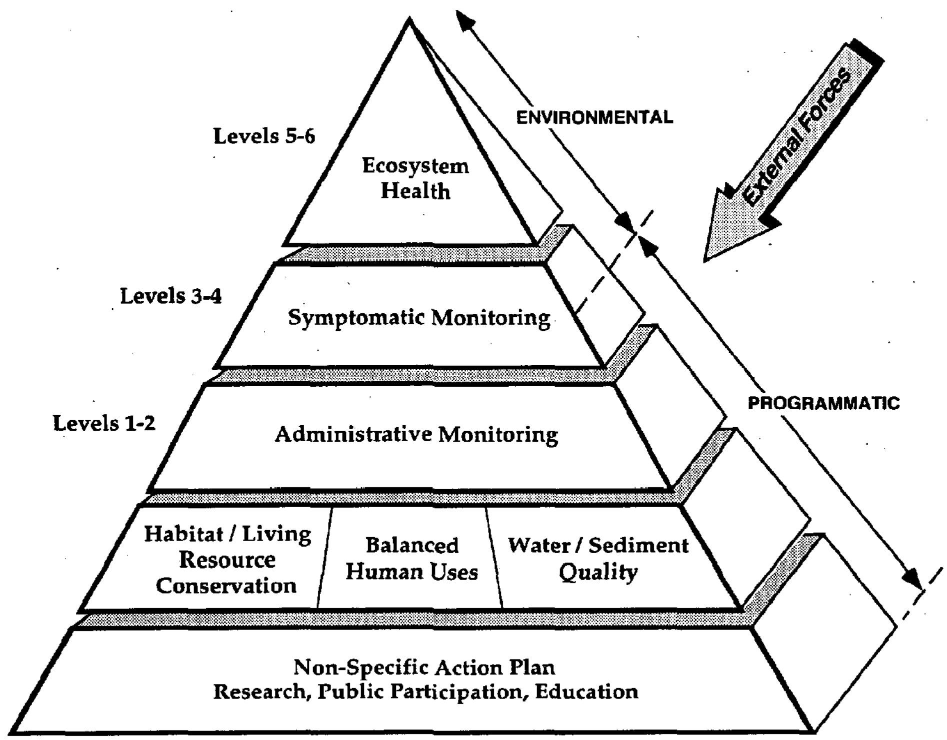

Figure 2-2. Integration of plan actions, monitoring and ecosystem health.

Programmatic Monitoring

To effectively, and completely, measure the success of the program it is necessary to establish a monitoring program which measures the success of the program in programmatic as well as environmental measures. Plan actions are usually specific activities designed to achieve a broader environmental objective and as such lend themselves to programmatic monitoring. As can be seen in Figure 2-2 it is the implementation of Plan actions which are the basis for anticipated changes in environmental health. Such monitoring will have two goals. First, is to monitor those activities or outcomes which are established in *The Plan*. This is intended to keep managers informed on the implementation status of various programs. Secondly, the monitoring program must help identify which programs are, or are not, achieving their intended outcomes. Such monitoring improves the accountability of the program to the public and local governments. With this information, management can redirect resources or make necessary modifications to the actions to achieve the desired result.

The Galveston Bay Program Office will have full-time staff responsible for monitoring action implementation and outcomes. The Galveston Bay Program Organization Plan will be structured to mirror the Plan initiatives. Every Plan Action will be managed by one of four organizational groups. These groups are Water/Sediment Quality, Natural Resources Uses, Monitoring and Research, and Public Participation. The Program will track implementation of Plan Actions, submit annual reports of these activities, implement any actions which *The Plan* delegates to the Program Office, and work with other lead agencies to develop assessment tools to measure the effectiveness of Plan actions.

Some cases will be relatively straight forward because only a few agencies may be responsible for implementation of a Plan Action. In other cases this is more complex. For example, Action NPS-1 of *The Plan* requires that local Galveston Bay watershed municipalities develop appropriate stormwater management plans. There will be numerous entities responsible for individually implementing this Action. Survey tools will be designed to track progress of such actions.

Many actions in the plan require development of educational and public outreach programs. The Public Participation and Education Action Plan calls for an active and involved public participation/public outreach program. For these actions we will be concerned with monitoring for desired outcome in addition to administrative tracking. Most public outreach actions and numerous other Plan actions such as water conservation education (FW-6), wetlands education (HP-1,2, and 4), anti-litter education (SD-5), and seafood safety risk communication (PH-1) may be evaluated by surveys designed to measure the effectiveness of the educational programs in addition to environmental monitoring. Where so delegated these survey tools will be developed by Program Office staff.

The programmatic element of the monitoring process will include an annual review of agency and local government implementation efforts. The Program will prepare an annual report outlining the specific actions taken toward achieving implementation goals. Biennial progress reports will be submitted to the Governor, the Texas Legislature and the public.

Environmental Monitoring

Generally, environmental monitoring lends itself to assessment of plan goals and objectives rather than specific plan actions. The environmental monitoring element of the Galveston Bay Regional Monitoring Plan has been developed to provide these higher level assessments of plan success. The Regional Monitoring Plan is a statistically sound, holistic monitoring effort designed to provide environmental data of known quality and confidence. The Regional Monitoring Plan is designed to collect data that can be compared to the quantifiable goals and objectives in each action plan. It also has a larger goal of providing knowledge of bay-wide ecosystems, their variability, and societal impacts both environmental and ecological.

A lack of fundamental, long-term ambient information was identified by characterization reports and Task Force members as a critical concern (Ward, 1992). These concerns will be addressed by building on existing monitoring programs, coordinating them to eliminate duplication of effort, increasing their scope and resolution, analyzing the data, eliminating information of dubious value, and making the results available to a diverse set of users in a timely fashion.

Understanding that no agency's mandate is broad enough for this undertaking, the Regional Monitoring Program seeks to promote a cooperative effort by all agencies, organizations, and stakeholders who participate in bay monitoring activities. The Program attempts wherever possible to integrate and expand current monitoring activities into a comprehensive and unified monitoring plan. **The plan was developed with full participation of all interested agencies to encourage cooperation, communication, and to maximize the potential for successful implementation.**

Principles for Building a Regional Monitoring Program

The primary purpose of the Galveston Bay Regional Monitoring Program is to assess whether progress towards achieving Galveston Bay Plan objectives is being made. To this end, the Galveston Bay Regional monitoring Program will provide fundamental, long-term information that will be used to characterize the status and long-term ambient conditions in the estuary.

The Regional Monitoring Plan has been designed to incorporate existing programs as its foundation. Goals were to reduce duplication of effort, expand the scope of the monitoring, and leverage resources by judicious selection of monitoring parameters. This was accomplished through the formation of the Galveston Bay Regional Monitoring Work Group. The Work Group membership was comprised of senior monitoring technical experts representing all agencies with ongoing monitoring activities in the bay area. The steps involved in the development of the monitoring program are shown in Figure 2-3.

Several design principals determined the nature and scope of the proposed regional monitoring program. These principals are:

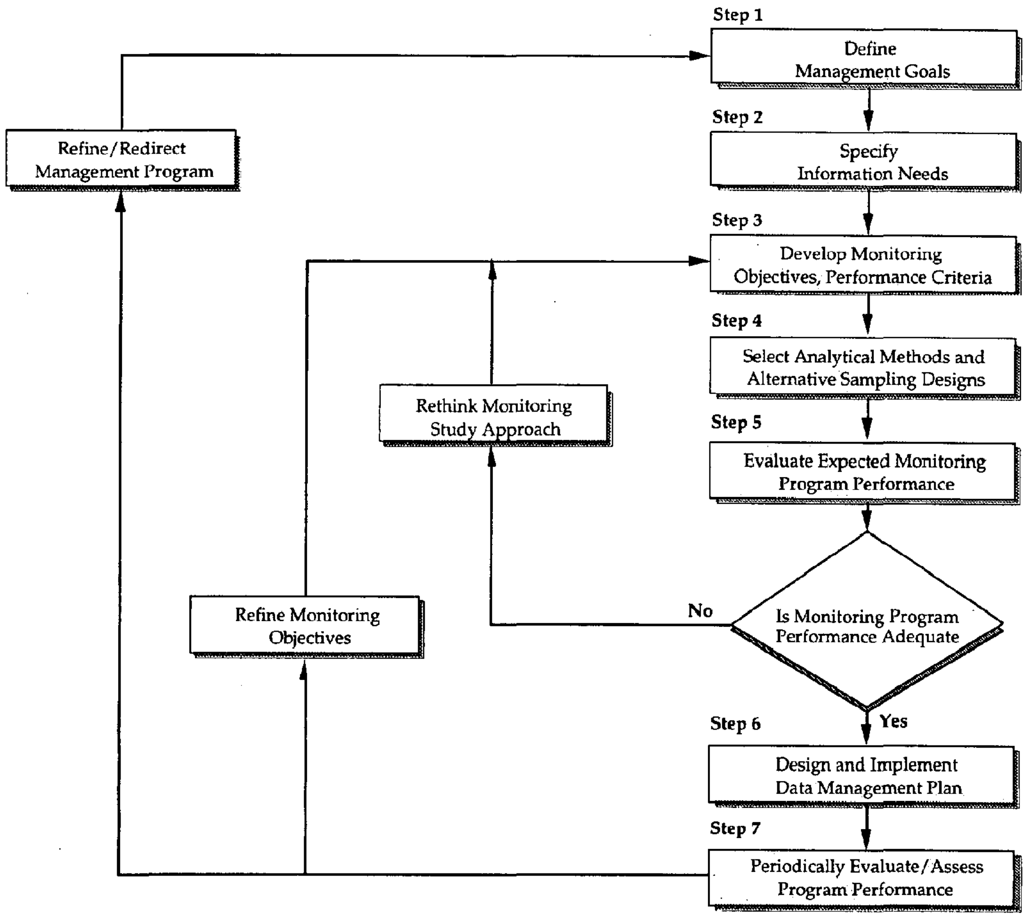

Figure 2-3. Steps in the design of the Galveston Bay Regional Monitoring Program (modified from USEPA, 1992a).

The Regional Monitoring Program will measure the status and effectiveness of Plan Actions.

First and foremost, Galveston Bay's Regional Monitoring Program will provide information to measure the progress and effectiveness of implemented Plan actions. This will be accomplished through the two monitoring elements previously discussed. These are programmatic and environmental monitoring. Programmatic monitoring includes the tracking of Plan implementation. An important Galveston Bay Program staff function will be to coordinate and communicate regularly with agencies identified as lead agencies for specific initiatives. Symptomatic monitoring, which may be either programmatic or environmental, assesses the effectiveness of the plan actions in measuring stressors to the ecosystem. Most actions will be assessed in a more general way through improvements in environmental conditions relative to identified bay problems.

The Regional Monitoring Program will characterize the status and trends of conditions in the bay.

Galveston Bay's Regional Monitoring Program will provide information describing the status and long-term trends of specified biotic and abiotic resources to be managed. Monitoring will include the collection of fundamental, long-term, descriptive measurements of parameters that are definable and meaningful. Sampling efforts will be coordinated to facilitate testing for meaningful correlation among several parameters as well as trends in parameters measured over time. The Regional Monitoring Program will monitor parameters that will allow a direct comparison to the goals and objectives specified in *The Plan*. With this information, bay managers, stakeholders, and the public can easily track the progress of *The Plan*.

Whenever possible, the Regional Monitoring Program will integrate existing monitoring efforts.

Galveston Bay's Regional Monitoring Program will incorporate existing and planned monitoring efforts or elements from these programs to minimize duplication of effort, maximize the development of essential information, and reduce the cost of the monitoring effort. Where gaps exist in monitoring coverage, efforts have been made to work with the appropriate agencies to supplement or develop the needed monitoring.

One of the primary goals of the Regional Monitoring Work Group was the adoption of standard parameter sets and comparable protocols for field sampling, analytical, and Quality Assurance/Quality Control (QA/QC) methods. Performance-based standardized sampling, analytical, and QA/QC protocols will be employed to ensure that the data collected by different groups participating in the monitoring program are directly comparable. Standardization and coordination of existing sampling efforts among local, state, and federal agencies will allow long-term sharing and use of all data collected as part of the Regional Monitoring Program.

An integral part of the Regional Monitoring Program is the development of a strong Quality Assurance program. This will be accomplished with the Galveston Bay Program office acting as a central figure in developing joint training programs and participation in laboratory quality assurance programs. An example of this is the Water Pollution Performance Evaluation Study available through the USEPA. All laboratories in the program will participate in this nationwide quality assurance program. The use of commercial suppliers of QA/QC samples will also be encouraged.

Ecological indicators will be used to assess status and trends of the bay's resources.

Measurement of all variables of all resources and all processes in the ecosystem is not feasible. The use of measurements that indicate the condition of valued habitats and resources, and the exposure to human stresses within habitats will significantly reduce the cost of the monitoring effort (Table 2-1). Galveston Bay's Regional Monitoring Program will measure indicators to characterize:

- Condition,
- Biological response,
- Stress exposure, and
- Sources of stress

Analyses of these indicator variables will be used to assess the current status and trends in the condition of key estuarine habitats and resources.

A multi-agency committee will be established to oversee and coordinate the Regional Monitoring Program.

Participants in the Regional Monitoring Workshop held in June 1992, unanimously called for the formation of a multi-agency committee to coordinate regional monitoring and research efforts. The Monitoring Work Group was formed in response to this call. The Monitoring Work Group is comprised of senior technical representatives from each of the agencies currently monitoring the Bay. In addition there is representation of agencies whose responsibilities for managing bay resources may be impacted by the Regional Monitoring Program. In the implementation phase the work of the Monitoring Work Group will be continued through formation of the Monitoring Steering Committee. It is highly recommended that the institutional membership of the current Work Group be included in this Committee.

It is the responsibility of this Work Group to develop and recommend to the Management Committee a final comprehensive environmental monitoring plan. This has been accomplished wherever possible through coordination of current monitoring activities. To accomplish this task, focus groups were formed for each of the major monitoring components of *The Plan*. Actions included in this effort are adoption of spatial and temporal sampling schemes, development of monitoring objectives and performance criteria directed at obtaining monitoring information required to evaluate the action plans. This included development of standard suites of parameters, sampling protocols, analytical methods and QA/QC procedures that will become the core of the monitoring program.

A data management strategy will be developed to ensure access to essential monitoring information.

Monitoring data for the Galveston Bay estuary are often not readily available and essential quality assurance information necessary to evaluate the comparability of data sets is frequently not preserved. A centralized data and information management system will be developed to ensure access to monitoring data. Current monitoring programs will continue to manage data for their specific mandates and purposes and agencies will maintain their own database systems. The focus of the Galveston Bay DIMS will be to help make this data useful beyond these purposes.

TABLE 2-1. DEFINITIONS OF CLASSES OF INDICATORS

Habitat indicators are physical attributes measured to characterize conditions necessary to support an organism, population, or community. Habitat indicators are used to describe conditions within habitats, as well as to interpret biological response and stress exposure information. For example, measures of sediment grain size describe the physical habitat and can assist in interpreting changes in benthic community structure.

Biological response indicators are characteristics of the environment measured to provide evidence of the biological condition of an organism, population, community, or ecosystem. They are used to assess the condition of valued habitats and biological resources.

Stress exposure indicators are characteristics of the environment measured to provide evidence of the occurrence or magnitude of contact with a physical, chemical, or biological stress. These measurements are used to identify and interpret detected changes in biological response indicators.

Stress source indicators are measurements that characterize human activities that can potentially affect changes in stress exposure and habitat condition. These measurements are used to characterize potential sources of stress and to assess the efficacy of specific management actions.

The system will have the following features:

- Centralized storage of data and information
- Standardized quality assurance reports for each data set
- Easy access and use
- Long term availability and flexibility
- System documentation and technical support

The data management system will be in place and operational prior to initiation of the monitoring program, and will provide the primary source of information for graphical and written summaries of the environmental data. These summaries will serve as tools to communicate information on the effectiveness of *The Plan* management actions and to build public awareness of monitoring program results.

Framework for Developing Components of the Regional Monitoring Program

The Galveston Bay Regional Monitoring Plan will delineate a program which is dynamic and subject to periodic re-evaluation of design, procedures, and findings to ensure its continued scientific credibility and its usefulness to policy makers and the public. To carry out these functions the Regional Monitoring Steering Committee was formed. It will be the responsibility of the Steering Committee to ensure that this re-evaluation take place in a rigorous manner, and that changes are made to the program as necessary. Guiding principles for the Regional Monitoring Program Steering Committee include:

- The Steering Committee will have responsibility for 1) review and modifications to monitoring elements, 2) creating new monitoring program elements, as appropriate; 2) developing new protocols; and 3) managing, interpreting, and reporting regional monitoring data.

- The Steering Committee will work to involve all parties (federal, state, and local agencies, research institutes, academic institutions, and volunteer organizations) engaged in monitoring and research in the estuary to maximize the usefulness and efficiency of public moneys spent on monitoring, but it will not dictate changes in ongoing agency monitoring programs.

- The Steering Committee will not make policy recommendations on regulatory or management issues. The Steering Committee will, however, seek to provide relevant information to policymakers and bring identified problems to the attention of policymakers and the public. It will establish policy on monitoring and recommend research needs related to monitoring efforts.

- The Steering Committee will be accountable to the Galveston Bay Council.

- The Steering Committee will be responsible for effective translation of monitoring data (its own and that of others) in terms that policymakers and the public can readily understand. A periodic report, the biennial State of the Bay, on conditions in the estuary will be produced and distributed through this committee..

The structure of the Regional Monitoring Program Plan is centered around five primary environmental monitoring elements identified by the GBNEP program office and described in *The Plan*:

- Water and sediment quality,
- Species population protection,
- Habitat protection,
- Freshwater inflow, and
- Public health protection.

The steps followed in the development are shown in Figure 2- 3. Products of each of these tasks are presented in the individual chapters addressing the primary management topics.

Step 1. Definition of resource management goals and objectives

Resource management goals and objectives describe the desired result of implemented Plan management actions. Statements of resource management goals provide a point of reference from which managers can assess whether conditions in Galveston Bay are improving, declining, or remaining the same. These statements specify the resource to be managed and an assessable or measurable end result. The resource management goals and objectives defined in Chapters 4-12 were developed by members of the Primary Topic Task Forces during development of the CCMP Action Plans.

Step 2. Identification of Data Information Needs

Identification of what data are needed came from GBNEP characterization reports, information needs identified by Primary Topics Task Force members, and discussions with GBNEP Task Force members. During April 1993, Task Force members held a series of technical workshops specifically to identify data information needs and to develop monitoring objectives for each of the five Primary Management Topics. The objective was to build upon the work described in GBNEP's characterization reports and to define data information needs and corresponding monitoring objectives. Key issues addressed during these meetings were:

- What data are needed and why,
- How data will be used as a diagnostic tool to assess progress toward management goals,
- Critical issues relating to the use of the data,
- Regional monitoring objectives, and
- Recommended monitoring parameters.

These meetings were successful in defining data information needs and broad monitoring objectives, but it was recommended that specific monitoring objectives be developed by members of the Regional Monitoring Work Group.

Step 3. Selection of Monitoring Objectives and Parameters

In June of 1994 the Regional Monitoring Work Group was formed. At this first meeting the group decided that five separate Focus Groups corresponding to the primary resource topics would be convened during these meetings. During the period from June to August, 1994 three rounds of meetings were held. Their aim was to further refine the broad monitoring objectives defined in the Primary Topic Task Force meetings and to select appropriate monitoring parameters to address these objectives.

Specific objectives were established for each of the environmental monitoring elements identified in the monitoring plan. These objectives are given within the chapters dealing with specific elements in the monitoring plan.

Step 4. Selection of Monitoring Methods

Once monitoring parameters were established work shifted to selection of appropriate monitoring methods. Tetra Tech, the contractor that developed the monitoring strategy document was contracted to develop a monitoring methods manual. The purpose of this project was to establish monitoring protocols to insure comparability of data collected by the monitoring effort and to assure an adequate level of data quality. Under this project, monitoring methods selection criteria (Table 2-2) were established to evaluate and select field sampling, analytical, and QA/QC methods for the Galveston Bay's regional monitoring program. As a result of this work Tetra Tech produced a document, *Protocols for Sample Collection and Analysis: Galveston Bay Regional Monitoring Program* which has been integrated into the monitoring plan. As part of this project a survey of ongoing monitoring programs was conducted and the following field sampling, analytical, and quality assurance/quality control (QA/QC) methods documents were reviewed:

- Methods and field operation manuals for ongoing monitoring programs in the Galveston Bay system,
- Method manuals for other National Estuary Programs (NEPs),
- Compendiums of monitoring methods for other regional and national monitoring programs, and
- Published papers describing state of the art methods.

A specific characteristic of the Galveston Bay Regional Monitoring Plan is the incorporation of existing monitoring methods that are routinely performed by different local, state and federal agencies. This approach was adopted to maximize the use of existing data sets, existing equipment and available technical expertise. This approach also allows for the full incorporation of each agency's mandated resource monitoring and protection responsibilities into the program. Use of existing methods will:

- Facilitate the evaluation and selection process since these methods are likely to have been previously tested and evaluated for accuracy, precision, sensitivity, comparability, and cost,
- Ensure that data collected by the regional monitoring program will be directly comparable to existing Bay data, and
- Reduces implementation costs since much of the equipment, skilled personnel, and procedural documents will already exist.

While existing methods have been given priority in the selection process state-of-the-art, inexpensive methods that provide data needed to assess management goals have been given considerable consideration especially when historical data are sparse and ongoing monitoring is limited. A technical and cost assessment of possible candidate methods was conducted to ensure that selected methods will be cost-effective and provide data needed to assess management goals.

Step 5 Selection and evaluation of Alternative Monitoring Strategies

In addition to selecting monitoring methods decisions must be made concerning spatial and temporal monitoring strategies. Specific monitoring strategies were

TABLE 2-2. SELECTION CRITERIA FOR MONITORING PROTOCOLS

- **Comparability**—the measure of whether data collected by the method is directly comparable to existing data for the same parameter

- **Cost**—the combination of implementation, equipment maintenance, and per sample costs

- **Sensitivity**—the measure of the ability to detect target parameters at low levels, sufficient to distinguish between seasonal variability and long-term trends.

- **Accuracy**—the measure of the agreement between the amount of a component measured and the amount actually present

- **Precision**—the measurement of the reproducibility of results when a method is repeated using a homogeneous sample under controlled conditions, regardless of systematic or constant errors that may affect the accuracy of the method.

- **Robustness**—the measure of method adaptability to the range of seasonal environmental conditions experienced across the estuary and to the range of expected target contaminant concentrations and non-target interference matrices and mechanisms.

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decided by the Regional Monitoring Work Group. Alternative sampling designs consist of determining:

- Distribution of sampling effort: random, systematic, or stratified,
- Allocation effort: sampling stations or replicates,
- Duration of monitoring program,
- Frequency of sampling, and
- Compositing strategies.

Management information needs were used to evaluate alternative sampling designs. Existing data and statistical power analyses were used to evaluate the performance of alternative sampling designs to provide identified information. Development of specific monitoring strategies are discussed in Chapters 4-12.

Step 6. Design and Implement Data and Information Management

One of the limitations of estuary monitoring systems across the country, including Galveston Bay, is that results from different monitoring programs are not easily compiled for ecosystem analyses. Agencies maintain different data bases and report formats, acquisition of data can be time-consuming, and no centralized data management system is currently available to report on overall trends. To alleviate these problems, a Data and Information Management System (DIMS) for Galveston Bay has been developed as part of the Regional Monitoring Program.

Questions addressed in the DIMS strategy include:

- Where will the data go?
- How will the data be stored?
- Who will maintain the data base?
- What QA checks will be performed on the data?
- How will access to the data base be made available and to whom will data be available?

Step 7. Evaluation and Assessment of Program Performance

To assure that the monitoring program is implemented and assessed on a regular basis, the Galveston Bay Council will establish a Regional Monitoring Program Steering Committee. A continued function of the steering committee will be to 1) establish final design specifications for Galveston Bay's Regional Monitoring Program; 2) oversee implementation of the program; 3) ensure comparability of monitoring efforts; 4) direct and approve future monitoring design modifications; and 5) secure institutional support for the program.

The Regional Monitoring Program Steering Committee will be a consortium of agencies, institutions, and organizations. It is highly recommended that the institutional membership of the Regional Monitoring Work Group be considered for inclusion in this body. The Regional Monitoring Steering Committee will be a governing body composed of representatives from

- Participating local, state, and federal agencies
- Environmental, private industry, and public interest groups
- Academic institutions

A Note on Organization

The first task was to catalogue the ongoing monitoring efforts in the Galveston Bay System. A summary of these activities is given in Chapter 3. The following chapters in the plan address the monitoring program for each of the primary management topics. The primary management topics are presented as:

Habitat/Living Resources Conservation
  Chapter 4 - Habitat Condition
  Chapter 5 - Species Distribution and Condition

Balanced Human Uses
  Chapter 6 - Public Health
  Chapter 7 - Freshwater Inflow
  Chapter 8 - Spills / Dumping
  Chapter 9 - Shoreline Management

Water and Sediment Quality Improvement
  Chapter 10 - Water and Sediment Quality
  Chapter 11 - Non-Point Sources of Pollution
  Chapter 12 - Point Sources of Pollution

Chapter 13 - Communicating Results: Data and Information Management

For each of the Primary Management Topic Chapters, a standard format described below has been developed.

Priority Problem: A brief discussion of the primary management concerns to be addressed. Serves as a rationale for subsequent management goals and objectives.

Management Goals and Objectives: A synopsis of Action Plan goals and objectives. Goals are broad, long-term solutions to the problem. Objectives are the environmental targets toward which future progress can be measured. These are usually more specific and shorter-term that goals.

Data Information Needs: Description of general data requirements necessary to provide information in assessment of management resource objectives. Describes information provided by the monitoring effort and how the data will be used.

Programmatic Monitoring: Detailing of those plan elements which do not lend themselves to environmental assessment.

Environmental Monitoring: A discussion of environmental monitoring techniques for which the Regional Monitoring Program will conduct data collection. This will include discussions outlining technical considerations in the design process (when appropriate). These include:

- Spatial and temporal design strategies,
- Monitoring parameters,
- Sampling and analytical methods, and
- Quality assurance and quality control.

Chapter 3

Overview Of Monitoring In Galveston Bay

This chapter summarizes existing monitoring efforts in the Galveston Bay Estuary upstream to the limit of tidal influence. A summary table and maps showing sampling locations for each monitoring program have been generated together with a description of that program.

The following information was requested from each of the agencies contacted:

- Monitoring Program Objectives
- Measurements Collected
- Locations of Sampling Sites
- Sampling Schedule
- Monitoring Methods
- Quality Assurance
- Data Management
- Monitoring Program Costs

Selected monitoring programs are summarized in Table 3-1, with more detail given in the following sections.

Federal Agencies:

U.S. Environmental Protection Agency

An ongoing assessment program of the USEPA is the Environmental Monitoring and Assessment Program (EMAP). USEPA EMAP goals (U.S. EPA, 1992,b) are to:

- Estimate the current status, trends, and changes in selected existing and newly-developed indicators of the condition of the Nation's ecological resources
- Estimate the distribution and extent of the Nation's ecological resources, and

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY

Summary of data collection activities, monitoring parameters, analytical methods, and quality assurance/quality control methods by the various agencies/organizations monitoring in Galveston Bay Estuary.

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Texas Natural Resource Conservation Commission (TNRCC)	68 stations	Water Column Chemistry: (see next column)	All stations - Routine	EPA Methods (1,2)		TNRCC requires that a minimum of one water quality monitoring program and one water quality sampling program undergo a quality assurance review each fiscal year.
		Sediment:	Water:			
	243 sampling activities/year	Chemistry - Ekman dredge	Temperature, conductivity, pH			
		Benthic macroinvertebrates:	dissolved oxygen (DO), salinity			
(Kirkpatrick, 1994)		*Peterson or Ekman dredge*				
(TNRCC, 1993)			Conventional pollutants:			Projects:
(TWC, 1991)		Nekton:	Biochemical oxygen demand (BOD)	405.1	1 mg/l	- water quality monitoring field data notebook
(Twidwell, 1993 and 1994)		Collection techniques	Total suspended solids (TSS)	160.2	10 mg/l	- standard instrument calibration and notebook
(U.S EPA, 1983 and 1986)		- Hook and line, trotline	*Oil and grease*	413.1	5 mg/l	- flow measurement records
		- Throwline, handline	Fecal coliform (FC)			- fecal coliform bacteria analysis records
		- 20' minnow seine with 1/4" mesh				- biological sample analysis records
		- Gill nets	Nutrients:			- proper data and sample collection procedures
		- Fish traps	Orthophosphorus	365.2	0.01 mg/l	- quality assurance review follow-up
		- Trawl	Nitrite - N	354.1	0.01 mg/l	
		- Cast nets	Nitrate - N	352.1	0.01 mg/l	Laboratory analysis will meet or exceed the
		- Water intake screens	Ammonia - N	350.1	0.02 mg/l	requirements set forth in the TNRCC Quality
			Total phosphorus	365.1	0.01 mg/l	Assurance program (3)
		Tissue - 4 preferred species	Chlorophyll a			
		- Hardhead (sea) catfish	Pheophytin a			Data storage:
		- *Pinfish*				- side by side data comparisons
		- Atlantic croaker	Total organic carbon (TOC)	415.1	1 mg/l	- computerized parameter value editing
		- Redfish (red drum)	Alkalinity	310.1	1 mg/l	
			Chloride	325.3	1 mg/l	
		Plankton:	Sulfate	375.4		
		- Kemmerer sampler	Total dissolved solids (TDS)	160.1	10 mg/l	
		- Van Dorn sampler	Volatile suspended solids (VSS)	624	10 mg/l	
		- Net hauls				
			Select stations:			
			Water and Sediment:			
			Organics - pesticides	608/8080	variable	
			Inorganics - alkalinity, hardness major ions			
			Metals	ICP - 6010	variable	
			Toxicity			
			Organisms:			
			nekton - tissue			
			plankton			
			benthos			
Texas Water Development Board (TWDB)	5 Stations	Semi-permanent moored stations using Data Sonde instrumentation	Water: Temperature, salinity, pH conductivity, DO			Instruments are checked and maintained on a regular basis.
(Brock, 1993 and 1994)	supports TCOON					
	8 Stations	Tide monitoring stations within Galveston Bay	Tidal elevation Some meteorological data			NOAA / NOS QA procedures Data inspected daily

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Texas Parks and Wildlife Department (TPWD) 1. Resource Monitoring (Bowling and Benefield, 1993) (Robinson, 1994) (TPWD, 1993a)	149 Stations Bay and Offshore Randomly selected from TPWD's grid system The number of usable grids varies for each gear type	Bay Bag Seines: 20 per month Targets juvenile finfish and shellfish 321 usable grids Bay Trawls: 20 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls 369 usable grids ICWW (Intercoastal Waterway) Trawls: 6 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls 77 usable grids Gulf Trawls: 16 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls Oyster Dredges: 30 per month Targets oysters: market, small, and spat 30-second dredge - 126 usable grids Beach Seines: May - November - 6 per month Targets adults in surf zone of front beach Beach Bag Seines: May - November - 6 per month Targets juvenile finfish and shell fish in surf zone Gill nets: 45 nets set during a 10-week period in the spring and fall Targets adult finfish in bay 4 segments of 150' each, 4 mesh sizes - 3" - 6" 1 per segment, shoreline to Gulf 252 usable grids Hook and line: As required by special study	Water: Temperature, salinity, pH turbidity, DO Weather conditions Wind direction Air temperature Organisms: Species Number Weight (select individuals) Length (subsample of 19 ind.) Sex and maturity Large, live fish tagged for growth and mortality			Guidelines follow TPWD Marine Resource Monitoring Operations Manual (4) Gill nets must be set within 1/2 hour of sunset and picked up no earlier than 1/2 hour before sunrise. Work on the last net must start before 11:00 a.m. Field data sheets are edited prior to submission for computer keying Computer printouts of field data are contrasted with field data sheets after computer keying
2. Coastal Resource Harvest Commercial Landings Program (McEachron, Campell, and Robinson, 1993) (Robinson, 1994) (TPWD, 1989)	130 - 140 seafood dealers Vessel captains	Seafood dealer submits reports - pertaining to commercial finfish, shrimp, crabs, oyster, and other marine life Length checks of target species - (200 per species) 5 target species - black drum, flounder, mackerel, red snapper, sheepshead Commercial bay/bait intercept program was implemented in May 1994 On-site interviews of vessel captains	Organism: Quantity by weight Number of species Price per pound Trip length Number of drags Total fishing time Minor bay fished Net size Mesh size Amount of live and dead shrimp landed Size of shrimp Species of catch			Guidelines follow TPWD Commercial Harvest Field Operations Manual (5)

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
3. Coastal Resource Harvest Recreational Landings Program (Robinson, Green, and McEachron, 1993) (Robinson, 1994) (TPWD, 1993b)	121 Sample sites 40 additional sites for detecting any change in status Sampling stratified and based on relative fishing pressure at each site. Determined by a computer generated relative pressure system.	On-site trip-end interviews	Boat registration number Trip length Number of people / residency Minor bay fished Gear: Bait - type and amount Fish landed: Species Total lengths (6 per species) Grade Species sought By-catch - released Trip satisfaction			Interviewers are periodically observed to monitor compliance with operating procedures Guidelines follow TPWD Marine Sport Harvest Operations Manual (6)
City of Houston/Department of Public Works & Engineering (CoH PW&E) (Glanton, 1993)	45 Stations in the tidal portions of major bayous		Water: probe Temperature, pH, conductivity, DO Total Residual Chlorine (TRC) Ammonia - N Nitrate - N BOD TSS FC			
City of Houston/Health and Human Services Department (HHSD) (APHA, 1992) (Fisher, 1993 and 1994) (Krentz, 1993) (U.S. EPA, 1983)	Field Operations : - 54 stream stations - all permitted wastewater dischargers	CoH - HHSD - The Bureau of Public Health Engineering has two groups conducting monitoring *Field Operations Unit -* Stations are all above tidal waters	Water: probe Temperature, DO			Participate in APG proficiency studies twice each year for each analyte listed (chemistry) *Field Notes, information reviewed after* computer entry
				EPA Methods (1)		
			BOD	405.1	4 mg/l	Duplicate
			Ammonia-N	350.1	0.05 mg/l	Duplicate, spike, external QC
			Sulfate	300	2 mg/l	Duplicate, spike, external QC
			TDS	160.1	20 mg/l	Duplicate
			TSS	160.2	4 mg/l	Duplicate
			Oil and grease	413.1	1 mg/l	External QC
			Chloride	300	2 mg/l	Duplicate, spike, external QC
			Trace metals:			
			As	206.2	2 mg/l	Duplicate, spike, external QC
			Cd, Cr, Du, Mn, Zn	200.7	10 mg/l	Duplicate, spike, external QC
			Ni	200.7	25 mg/l	Duplicate, spike, external QC
			Se	200.7	1 mg/l	Duplicate, spike, external QC
			Hg	245.2	0.5 mg/l	Duplicate, spike, external QC
			Pb	200.7 / 239.2	40 mg/l	Duplicate, spike, external QC
			FC	Standard Methods (7) 9221 E(1.)	2 / 100 ml	FC bacterial analysis records 9221 E(1.)
	Quality Assurance Group : - Lake Houston and watershed - 6 major Houston bayous	Quality Assurance Group - These bayou stations are all at USGS monitoring stations and include the lowest USGS station at each bayou	Water: probe Temperature, DO			Field notes, information reviewed after computer entry
				EPA Methods (1)		
			pH	150.1		Buffer check
			TDS	160.1	20 mg/l	Duplicate
			Sulfate	300	2 mg/l	Duplicate, spike, external QC
			Chloride	300	2 mg/l	Duplicate, spike, external QC
			FC	Standard Methods (7) 9221 E(1.)	2 / 100 ml	Standard Methods (7) FC bacterial analysis records

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Harris County Pollution Control Department (HCPCD) (APHA, 1992) (Barrett, 1993 and 1994) (Tyer, 1994)	9 Stations - Houston Ship Channel 6 Stations - on the San Jacinto River Each industrial discharger Municipal dischargers		Water: probe Temperature, DO, flow	Standard Methods (7) DO = 4500-0 G		Calibrate meter prior to each use
			pH	4500-H+		2 buffer standardization and read 3rd buffer prior to each analytical run; restandardize/ reanalyze violations
			TOC	5310B	1 mg/l	Standardize prior to each analytical run (optional: check calibration with independent standard), check calibration about every 10 samples and at end of run. Reanalyze violations, including spike analysis
			Trace metals: As Cd Cr, Ni Cu, Mn Zn	 3111/3113 3111 3111 3111 3111	 0.001 mg/l 0.002 mg/l 0.02 mg/l 0.01 mg/l 0.005 mg/l	Two point calibration prior to each analytical run; check calibration about every 10 samples. One replicate analyzed with each run. Reanalyze violations, including spike analysis.
			Total solids (residue)	2540B		Control dish (no sample)
			TSS	2540D		One random replicate with each analytical run and/or replicates on any suspected violations; reanalyze any violation without previous replicate; water blank and control crucible (no sample) with each run
			Ammonia - N	4500	0.03 mg/l	Standardize prior to each analytical run; one random replicate analyzed with each run; check calibration with two different standards (concentrations) one during run and other at end of run
			FC/Fecal Streptococcus (FS)	Modified 9222D/9230C	10 / 100 ml	Periodically analyze replicates, system blank, air density plate and known active sewage
			Volatile acids (VA)	Qualitative		Periodically analyze known cyanide solutions
			Sulfide	Qualitative		Periodically analyze known sulfide solutions
			Chloride	Harris County Method	7 mg/l	Periodically analyze chloride standard
Galveston County Health District Pollution Control Division (GCHD) (APHA, 1989) (Fogerty, 1993 and 1994) (Wright, 1994)	120 Stations including Galveston Island - beach, bayside, ship channel, and bayous Mainland county bayous, creeks, some drainage ditches Texas City Ship Channel and Dike	Collect water quality samples only Grab samples usually, composites rarely Samples collected on monthly, bi-monthly, and tri-annual basis	Date and time Wind direction Wind speed Cloud cover Rainfall Days prior rainfall and amount Tide (high/low) Flow direction (in/out) Sample depth Air temperature Water temperature	Use NOAA weather information for: wind direction, speed, and rainfall Use daily rainfall data from wastewater treatment plants throughout county		Field meters are calibrated using manufacturers guidelines before each use. Manufacturer services meters as necessary. Laboratory uses standard QC methods (blanks, spikes, controls, and duplicates) EPA required controls implemented for those tests performed for contracted services for cities

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
	Permitted dischargers		DO, salinity, conductivity	YSI field meters		
			pH	Corning or Orion meters 4500-H Standard methods		4500-H Standard metho
	Complaint sampling		Water color			
			Observed turbidity or secchi disc	Standard Methods (8)		Standard Methods (8)
			BOD	5210 B	2 mg/l	
			TSS	2540-D		
			FC			
			Occasionally:			
			Chemical oxygen demand (COD)	5220 B		
			Ammonia-N	4500 NH3 B	0.01 mg/l	
			Total phosphorus	4500-P-B-5	0.02 mg/l	
			Oil and grease	5520 B		
			Extra capabilities:			
			TDS	2540-C		
			Volatile suspended solids (VSS)	2540-E		
			orthophosphate	4500-P-B	0.01 mg/l	
Chambers County Environmental Health Department	Trinity Bay - respond to septic/ sewage complaints	No monitoring programs in Galveston Bay				
(Jackson, 1994)	Lake Anuhuac		FC			
U.S. Environmental Protection Agency (EPA)						
Environmental Monitoring and Assessment Program (EMAP) (Heimuller and Valente, 1991) (Hornig, 1993) (Summers et al., 1992) (U.S. EPA, 1983 and 1991)	5 Stations in the vacinity of 5 marinas 6 Stations in East Bay Bayou	Water quality - two models of dataloggers - Surveyor II - instantaneous measurements - Data Sonde 3 - continuous measurements Water clarity - LICOR L1-1000 containing a submersible light sensor Light penetration - Secchi disk Fish: Trawling with a 16', high rise otter trawl with a 2.5 cm mesh cod end - towed for 10 minutes against tide Target species for tissue contaminants: - shrimp (brown and white) - Atlantic croaker - catfish (hardhead, gafftopsail, and blue) Composite of 4 - 10 individuals per site Bivalves: Modified oyster dredge with collection bag towed over the bottom - 5 minutes at approximately 1 m/s	Water: probe Temperature, salinity, pH, DO Water clarity Water depth Light Marine debris Fish: Number of species Total abundance Gross pathology Bivalves: Total abundance Species composition Shell length Fish and bivalve tissue: Pesticides, PCBs Heavy metals Benthic community parameters Grain-size analyses			Crew training and sample collection: - chief training - crew training - field certification / auditing - testing and scoring of personnel Water quality measurements: Field quality control checks - instantaneous and continuous measurements - All datalogging units are calibrated with documentation within the 24-hour period preceding their scheduled use - side by side measurements between Data sonde and Surveyer (standard) - QC data compiled and evaluated to determine the frequency of acceptable and unacceptable adherence to QA guidelines Laboratory certification and chemical analyses: - laboratories must pass a certificaiton prior to analyzing any samples - usual QC methods (blanks, spikes, controls, and duplicates) - standard reference materials (SRMs) with certified values for metals and organics

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
               R-EMAP-TX program	 33 Stations - 29 systematic grid sites - 4 randomly selected bay sites	Benthos: Young - modified Van Veen grab which samples a surface area of 440 square cm - 3 grabs at base, index, or supplement sites - 5 grabs at indicator sites Grain-size analyses: Small core (60 cc) from each grab - sieved	Sediment: Toxicity Ampelisca abdita Mysidopsis bahia Alkanes and isoprenoids PAHs Pesticides, PCBs Heavy Metals: Ag, Al, Cr, Cu, Fe, Mn, Ni, Pb, An As, Cd, Sb, Se, Sn Hg Butyltins TOC Sediment: Detailed chemistry Benthic communities	 10-day acute bioassay 4-day acute bioassay GC/MS GC/ECD ICP-AES ICP-AES GFAA CVAA		Laboratory testing and analyses: - scheduled recounts and resorts for benthic assessments - experimental controls for sediment toxicity testing - scheduled replication for sediment characterization - use of blank, spikes, and standards for chemical assessments - EMAP-E personnel visit each of the laboratories at least once while EMAP-E analyses is occurring
U.S. Geological Survey (USGS) (Fisher, 1994) (Liscum, 1993)	2 stage gages 4 automatic monitoring stations 12 stations	USGS - stage gage - Moses Lake - stage gage - Hwy 90 at San Jacinto River Freshwater inflow monitoring	stage and precipitation stage Water: probe Temperature, salinity, pH conductivity Surface water elevation Surface water elevation - hourly Freshwater inflow - hourly 4 to 6 samples per year BOD COD FC FS TOC Nutrients Selected pesticides/herbicides Specific conductance Water temperature			Instruments are checked, maintained, and calibrated on a regular basis
Galveston Bay Foundation (GBF)	Approximately 34 stations in tidal segments	Grab samples are taken 1 foot below surface Samples are collected weekly or bi-monthly	Water: temperature, DO, pH, salinity, conductivity, turbidity Weather: wind direction, intensity, days since last rainfall, air temp. Other: total depth, water level, odor, site observations, tide, color	Standard Methods: 2550-B. 4500-o C 4500-H B 2510 B		GBF follows the Texas Watch QAPjP; Monitors receive Texas Watch (TNRCC) training Monitors participate in 2 QC sessions per year. Conductivity pens are calibrated prior to each monitoring event. DO chemicals are changed every 6 months.

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
U.S. Fish and Wildlife Service (USFWS)	Entire estuary - every 10 years	USFWS - National Wetlands Inventory - program of mapping wetlands using aerial photography	Vegetation groups:	Photo analysis Ground truthing		
(Special Study) Galveston Bay National Estuary Program (GBNEP) (Carr, 1993) (Jensen et al., 1993)	24 Stations 16 stations selected in depositional zones away from known point source discharges 8 stations selected based on specific areas of concern A GPS navigation receiver was used to determine station locations.	Sediment: - collected with a 4" diameter coring device Benthos: - collected with a 2" diameter coring device	Water: probe Temperature, salinity Water depth Sediment: Trace metals: Al, Br, Be, Cr, Cu, Fe, Mg, Mn, Ni, Tr, Vd, Zn As, Cd, Pb, Se Hg PAHs Pesticides, PCBs TOC AVS Toxicity: *Grandidieralia japonica* Pore water: DO, pH, hydrogen sulfide Temperature, ammonia Toxicity: gametes Arbacia punctulata Benthic community parameters Total abundance Species composition Species diversity Species richness	DCP DCP GFAA CVAA MS in the SIM mode CGC oulometer TOC analyzer GFAA 10-day solid-phase bioassay Fertilization test Morphological development assay		NS&T QA/QC Procedures Morphological development assay
National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program (NS&T) (Presley and O'Conner, 1993)						NS&T Program Methodology - performance based Analysis of reference materials and control materials is required

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
1. National Benthic Surveillance Project (NBSP) (NOAA, 1993)	9 Stations : a nominal site center has been defined for NBSP sites as an area 2 km in diameter and is revisited for sample collection	Sediments were collected concurrently with fish specimens at each NBSP site Sediment: - specially constructed box corer - standard Smith-MacIntyre bottom grab the water was drained before sediment was take Fish: - primarily collected by otter trawls towed by NOAA vessels - occasionally by hook and line or gill nets	Sediments: Organic compounds: Pesticides, PCBs PAHs Coprostanol	 GC/ECD GC/FID/MS GC/FID	 0.0001 ug/g 0.0010 ug/g	Trace organic analytical procedures - internal standards are added at the start and carried through analyses Calibration checks - plus or minus 10% of the accuracy based value for standards
			Major and trace elements: Si, Al, Fe Cr, Zn, Mn Ag, As, Cd, Cu, Ni, Pb Hg	 FAA FAA, GFAA GFAA, FAA, HAA CVAA	 Ag, Cd, Hg = 0.005 ug/g Cr, Pb = 0.2 ug/g As, Cu = 0.05 ug/g	All samples must be quantified within the calibration range
			Clostridium perfringens TOC Moisture content Particle size	plate count CHN analyzer drying at 120 degrees C Wet sieving techniques		Method Detection Limits (MDLs) are calculated and reported annually - Since 1989, method for calculating MDLs is that used by the EPA If EPA method is not used - the procedure is described in detail
			Fish Tissue: Organic compounds: Pesticides, PCBs PAHs - stomach contents PAH metabolites - bile	 GC/ECD GC/FID/MS HPLC/FID	 0.001 ug/g 0.01 ug/g 0.01 ug/g	Precision - defined limits Accuracy - defined limits A minimum of 8% of an analytical sample string should consist of blanks, reference or control materials, duplicates, and spike matrix samples
			Major and Trace elements: Al, Ag, As, Cd, Cr, Ni, Pb, Sb, Se, Sn, Tl Fe, Mn, Cu, Zn Hg	 GFAA GFAA FAA CVAA	Ag, Cd, Hg = 0.001 ug/g Cr, Pb = 0.04 ug/g As, Cu = 0.01 ug/g	Data acceptability criteria reported annually Intercomparison exercises Quality assurance workshops Development of standard reference and 0.01 ug/g control materials
			Tissue dry weight Otoliths or scales - fish age	Oven drying		
2. Mussel Watch Program (MWP) (NOAA, 1993)	6 Stations: Sites were defined using Global Positioning System Technology	When taken, sediment samples were collected concurrently with bivalve samples Sediments: - stainless steel box core - Teflon-coated sampling scoop Oysters: American oyster - hand (preferred), tongs, or dredge	Water: probe Temperature, salinity, depth			National Institute of Standards and Technology (NIST) trace organic exercises - performance based National Research Council (NRC) trace element exercises - performance based
			Sediments: Organic compounds: Pesticides, PCBs PAHs Coprostanol	 GC/ECD GC/MS GC/FID	 0.0001 ug/g 0.0010 ug/g	
			Major and trace elements: Al, Cr, Mn, Fe Ni, As, Se, Ag, Cd, Sn, Pb Cu Zn Hg	 NAA GFAA GFAA, FAA FAA CVAA	Ag, Cd, Hg = 0.005 ug/g Cr, Pb = 0.2 ug/g As, Cu = 0.05 ug/g	
			Clostridium perfringens TOC Moisture content Particle size	plate count carbon analyzer 4 hours at 45 degrees C Dry sieved		
			Oyster tissue: Organic compounds: Pesticides, PCBs PAHs	 GC/ECD GC/MS	 0.001 ug/g 0.01 ug/g	

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
			Major and trace elements: Al, Mn, Fe, Zn Cu Cr, Ni, As, Se, Ag, Cd, Sn, Pb Hg Tissue dry weight Shell size Radionuclide samples - 1991 Gonadal index	 FAA FAA/GFAA GFAA CVAA Oven drying	Ag, Cd, Hg = 0.001 ug/g Cr, Pb = 0.04 ug/g As, Cu = 0.01 ug/g	0.01 ug/g
National Marine and Fishery Service (NMFS) (Zimmerman, 1993)						
1. Baseline Production	Variable stations in West Bay marsh	Fish, shrimp, and crabs are sampled using drop samplers	Organisms: Densities of target species Biomass			
2. Brown Shrimp Catch Program		NMFS - brown shrimp - Interviews with bait dealers and fishermen - Reviews of fishermen's logs	Catch per unit effort Pounds per hour			
3. Post Larval Shrimp Program (discontinued in 1993)	6 Stations	Samples are collected with a 5' long, small-meshed, modified hand-held beam trawl	Water: probe Temperature, salinity Tide condition Catch per 100 square meters of bottom area Length (size of shrimp)			
Texas Department of Health (TDH) (APHA, 1970) (Wiles, 1993)	104 Stations - approved shellfish harvest areas - conditionally approved waters	Water samples are collected 2 feet under the water surface while other parameters are measured by probes.	Water: probe Temperature, DO, salinity Weather conditions: Air temperature Rainfall Wind direction Wind velocity Tide conditions FC			National Shellfish Sanitation Program NSSP QA/QC Guidelines (9)

TABLE 3-1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
U.S. Army Corps of Engineers (USCE) 1. Dredged Material Monitoring Program Galveston District (Medina, Hauch, and Arhelger, 1993) (U.S. EPA, 1986 and 1991)	6 core stations in the Houston Ship Channel	Samples collected by a bottom grab	Heavy Metals As Cd Cr Cu Ni Pb Zn Se Hg Oil and grease PCBs PAHs Pesticides Grain-size analyses Toxicity Bioaccumulation	EPA methods (2) 7060 7131 7191 7211 7521 7421 7951 7740 7470 -day solid phase bioassay 28-day bioaccumulation		Dredged Material Testing Manual (2) EPA methods (2) QA/QC Guidelines (10) - 10% of laboratory samples are field duplicates - One sample of every 10 - 20 samples are analyzed in triplicate
2. Open Bay Disposal Dredged Material Program - Waterways Experiment Station (3 year program scheduled to finish in 1994) (Clark and Ray, 1993) (U.S. EPA, 1986 and 1991)	30 Stations: Open Bay	Samples collected with a box corer Sediment profiler	Sediment: Sediment profile imagery Grain-size analyses Sediment carbon Redox potential Surface relief Benthos parameters	EPA methods (2)		Dredged Material Testing Manual QA/QC Guidelines (10)

NOTES:

(1) U.S. EPA. 1983. Methods for chemical analyses of water and wastes, 2nd Edition. EPA 600/4-79-020. U.S. Environmental Protection Agency, Environmental Support Laboratory.
(2) U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes, 3rd Edition. EPA SW-846. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.
(3) TNRCC. 1993. Quality Assurance Project Plan for Environmental Monitoring and Measurement Activities, Surface Water Monitoring. Texas Natural Resource Conservation Commission, September 1993.
(4) TPWD. 1993a. Marine Resource Monitoring Operations Manual. Texas Parks and Wildlife Department, January 1993.
(5) TPWD. 1989. Commercial Harvest Field Operations Manual. Texas Parks and Wildlife Department, January 1989.
(6) TPWD. 1993b. Marine Sport Harvest Monitoring Operations Manual. Texas Parks and Wildlife Department, July 1993.
(7) APHA. 1992. Standard Methods for the Examination of Water and Wastewater, 18th Edition. American Public Health Association, Washington, D.C.
(8) APHA. 1989. Standard Methods for the Examination of Water and Wastewater, 17th Edition. American Public Health Association, Washington, D.C.
(9) APHA. 1970. Recommended Procedures for the Examination of Seawater and Shellfish. American Public Health Association, Washington, D.C.
(10) U.S. EPA. 1991. The Near Coastal Laboratory Procedures Manual. Environmental Monitoring and Assessment Program. U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Cincinnati, OH.

**** ABBREVIATIONS:**

AES -	Atomic emission spectrometry	GC -	Gas chromatography
CGC -	Capillary gas chromatography	GFAA -	Graphite furnace atomic absorption
CHN analyzer -	Carbon-hydrogen-nitrogen analyzer	HAA -	Hydride generation atomic absorption
CVAA -	Cold vapor atomic absorption	HPLC -	High performance liquid chromatography
DCP -	Direct coupled plasma	ICP -	Inductively coupled plasma
ECD -	Electron capture detection	MS -	Mass spectrometry
FAA -	Flame atomic absorption	NAA -	Neutron activation analysis
FID -	Flame ionization detector	SIM -	Selected ion monitoring
GC -	Gas chromatography		

- Seek associations between selected indicators of natural and human stresses and indicators of the condition of ecological resources.

Sampling stations are systematically distributed throughout the estuary according to gridded areas — approximately 18 km between each sampling station. A quarter of these gridded areas are sampled every year. During each sampling event, a random sample station is located within those grids to be sampled. All samples are collected in the summer generally August to September. EMAP-E indicators focus on fish and benthic community structure, contaminant levels in fish and sediment samples, sediment toxicity, and dissolved oxygen profiles.

In addition to EMAP-E the EPA has conducted higher resolution sampling in Galveston Bay under the Regional-EMAP (R-EMAP) . The purpose of the R-EMAP pilot program for Galveston Bay was to follow-up on areas flagged during previous EMAP-E sampling. R-EMAP projects will also demonstrate the utility of applying EMAP design and indicator concepts to address problems of a smaller spatial and temporal scale. Sediment collection and analyses followed EMAP Near Coastal protocols. Analyses of sediment chemistry, sediment toxicology, and benthic community structure were conducted. The project will initially be limited to one round of sampling, conducted in mid-September 1993. The decision to conduct a follow-up of the project will be made after examination of the data. The proposed cost of the program is approximately $250,000. (K. Summers, U.S. EPA, personal communication)

The R-EMAP pilot project for Galveston Bay consisted of randomly sampling 33 stations uniformly distributed about the bay (Figure 3-1) Bottom sediment samples were collected from the 29 grid and 4 bay stations for detailed chemistry and benthic community analyses. Three duplicate samples are randomly selected from the grid site samples for chemistry analysis and as a quality assurance practice. Five marina stations were sampled for sediment chemistry, benthic communities, and water Tri-Butyl-Tin (TBT) analysis. The six East Bay Bayou stations were sampled for 1) fish tissue pathology and chemistry and for 2) sediment chemistry and toxicity analyses. One additional fish chemistry analysis is also conducted as a quality assurance practice.

United States Geological Survey

USGS operates a total of 16 stations which monitor water quality in either tidally affected sections of Galveston Bay or freshwater inflow to the Bay (F. Liscum, USGS, personal communication). These stations include four continuous four-parameter monitors operated for the City of Houston located on tidally influenced reaches (Buffalo Bayou at the Turning Basin, Buffalo Bayou at McKee St. (just below the confluence with White Oak Bayou), Buffalo Bayou at Shepherd Drive, and White Oak Bayou (just above the confluence with Buffalo Bayou). Continuous monitoring parameters are water-surface elevation, temperature, dissolved oxygen and specific conductance. These data are available on a near real-time basis

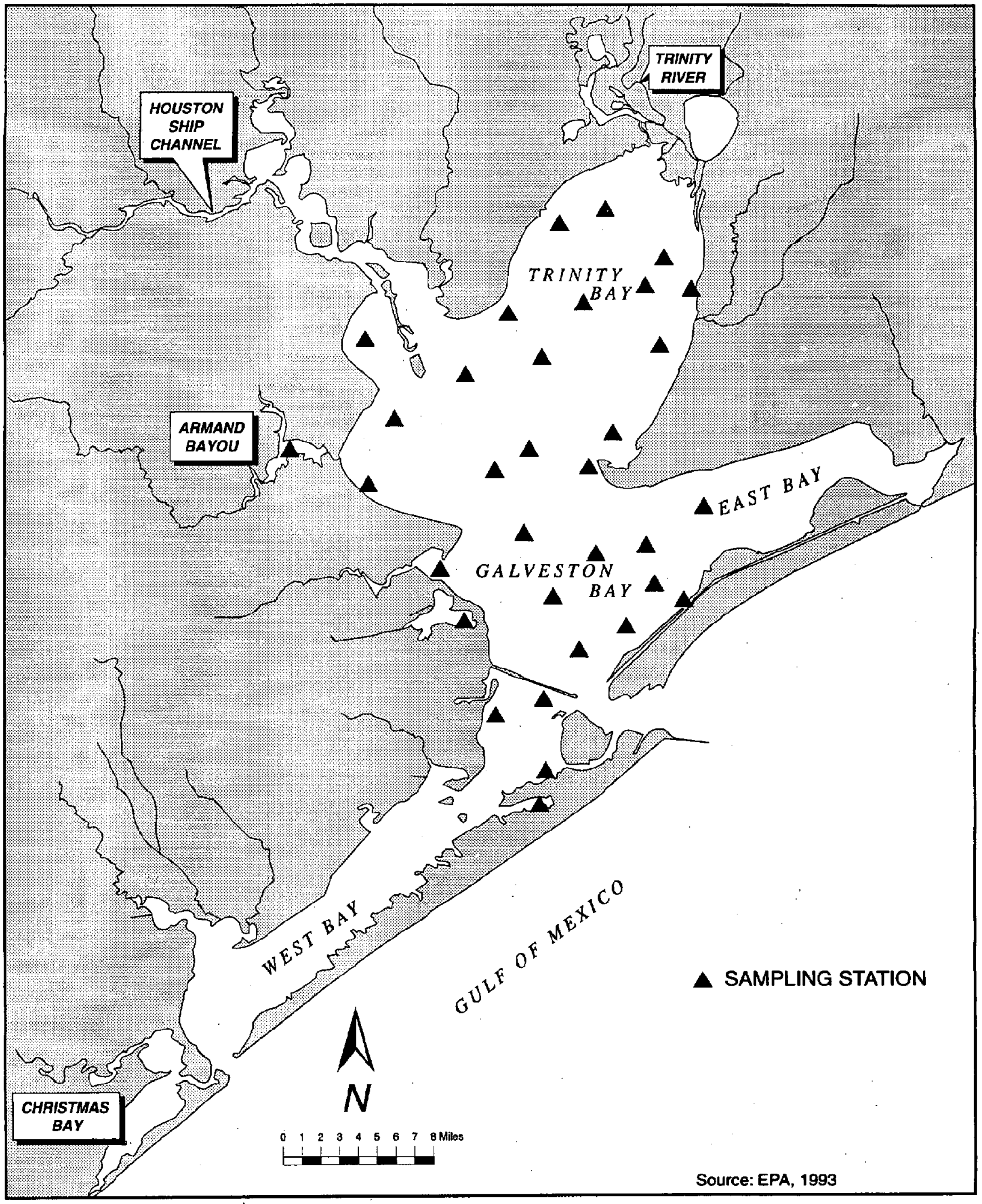


Figure 3-1. U.S. EMAP sampling stations in Galveston Bay.

through access via the GOES satellite system. Annual cost (1994 FY) for each station is about $26,500.

The twelve other stations are located to help define freshwater inflow to Galveston Bay. These include four sites to better define the impacts from the urban areas of Houston (located on the Brays, Sims, Hunting and Greens Bayous), seven sites to define the contribution from Lake Houston (sites located on Lake Houston and six tributaries, Cypress Creek, Spring Creek, Luce Bayou, West Fork San Jacinto River, Caney Creek and East Fork San Jacinto River) and one site to help define the input from the Trinity River (located at Romayor). These sites are paired with USGS flow stations and are equipped with automatic samplers. In addition to hourly water surface elevation and flow data, the following data are available for these sites for collected samples:

> BOD, CBOD, FC, FS, TOC, minor elements (calcium, magnesium, alkalinity, sulfate etc.), nutrients, selected herbicides and pesticides, specific conductance and water temperature.

Sample collection frequency varies in the order of 4 to 6 times a year, depending upon agency requirements. The cost for operating these stations ranges from about $15,000 to almost $25,000, dependent on the sampling frequency.

The recorded data from USGS stations are available in the Water Resources Data Reports publications series. These data are also available by other sources from USGS:

1) Through NAWDEX, i.e., main frame access to USGS archives and on-line data storage. TNRIS is the assigned access point for Texas.

2) Hard copy (i.e., printouts) and/or computer compatible media requests are available by written request.

3) Access over computer communication networks are available by entering into an agreement with USGS (MOU - Memorandum of Understanding).

None of the monitoring stations fall within the boundaries of the base map used in this chapter. These will be critical stations in the tributary monitoring effort.

United States Corps of Engineers

The U.S. Corps of Engineers is presently conducting two sampling programs in Galveston Bay. The first is the Dredged Material Monitoring Program by USCE Galveston District (R. Medina, R. Hauck, and M. Arhelger, U.S. Army Corps of Engineers, Galveston District, personal communication). As shown in Figure 3-2, six stations in the Houston Ship Channel are regularly monitored for dredging

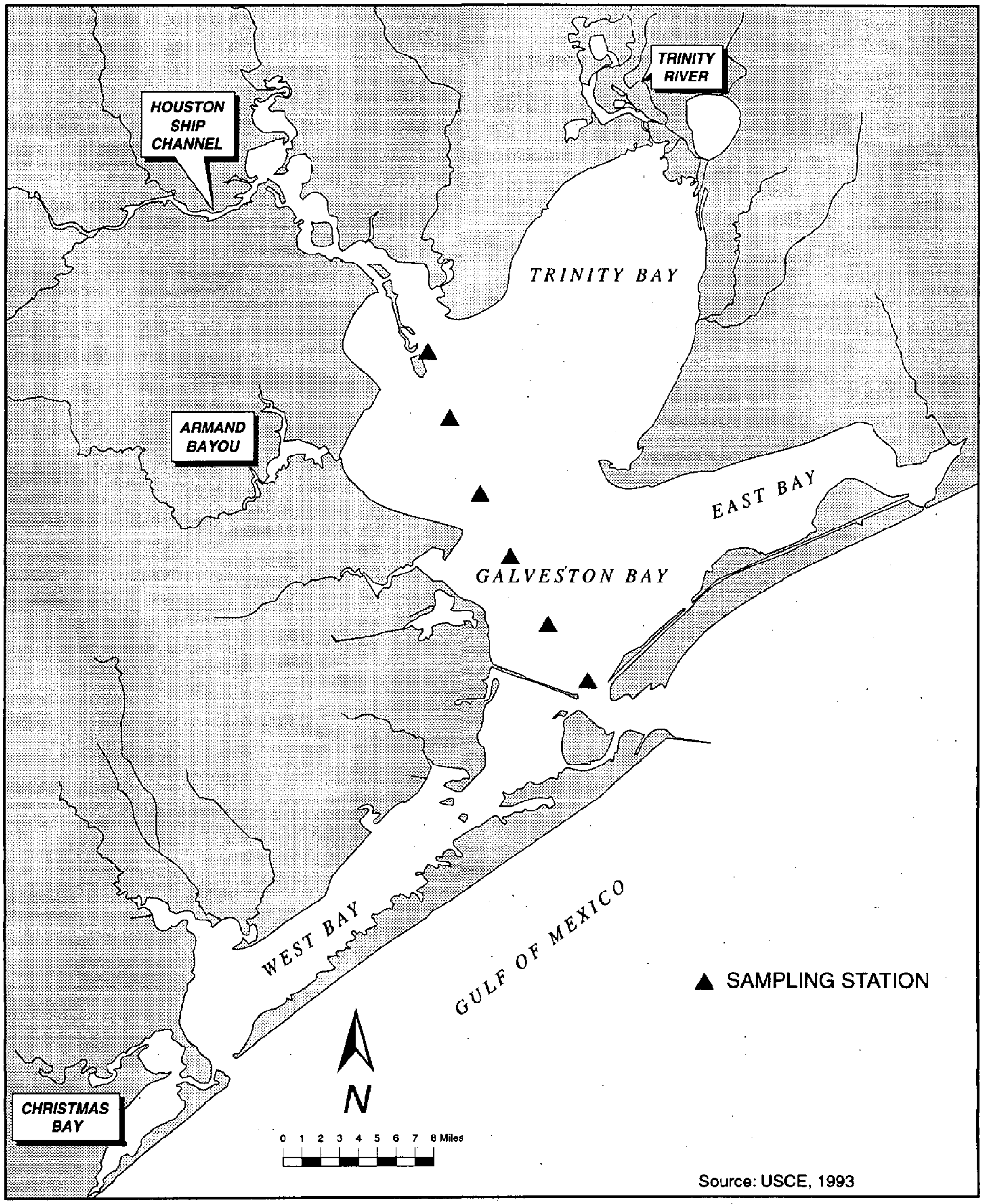


Figure 3-2. USCE Galveston District Houston Ship Channel "core" monitoring stations.

activities. Other estuarine stations are also monitored for specific projects. All channels currently being dredged are sampled once before dredging and six times after dredging. Maintained channels are monitored every three years. Samples are collected by bottom grab and analyzed for metals, oil and grease, PCBs, PAHs, pesticides, grain sizes, toxicity, and bioaccumulation. The collected data are not stored at USCE but are retained by a private contractor. The annual cost for the monitoring program is variable depending on the number of dredgings conducted in one year. However, the cost per sampling effort is approximately $76,000.

The second USCE sampling program in Galveston Bay is the Open Bay Disposal Dredge Material Program conducted by the Waterways Experiment Station (D. Clarke and G. Ray, U.S. Army Corps of Engineers, Waterways Experiment Station, personal communication). This is a three-year research program, now in its final year. Thirty stations are monitored two to four times per year. Sixteen stations are located in the upper bay areas. Fourteen are located in the lower bay areas. The monitoring is conducted by box corer and sediment profiler for sediment profile imagery, benthos characterization, grain size, sediment carbon, Redox potential, surface relief, and benthic succession. The collected data are stored in an in-house computer. While this program is not an ongoing monitoring program, it is mentioned here because of the valuable information that will be provided for bay sediments.

United States Fish and Wildlife Service

The USFWS does not conduct a routine monitoring program such as the TNRCC or USGS programs (B. Cain, USFWS, personal communication). USFWS activities are generally limited to short-term special studies to address particular issues. The USFWS does carry out the National Wetlands Inventory (NWI), which is a program of mapping wetlands nationwide using stereoscopic analysis of high altitude aerial photography and historical topographic data. Areal changes in open-water, wetlands, and developed land are assessed and future changes projected. This survey is performed at a roughly 10-year interval. The last NWI survey/projection for Galveston Bay was funded as a GBNEP characterization project (White et al., 1993).

USFWS is also involved with several bird surveys. The Mid-winter Waterfowl Survey is conducted in cooperation with the Texas Parks and Wildlife Department. This survey consists of a systematic scheme of sampling along transects and another less systematic scheme of counting birds in general locations. These data provide information on abundance of waterfowl by species and by transect, or by general location within the surrounding waters of Galveston Bay System (Slack, 1992). Another bird data set important to the GBRMP monitoring effort is the Shorebird Survey of Bolivar Flats. The USFWS has conducted irregular monthly surveys since 1980 at the Bolivar Flats. These surveys are conducted in the beach and marsh habitats of the flats by one observer using a spotting scope to identify all species of birds (Slack, 1992).

Plans for monitoring wildlife refugees are being developed. This effort is expected to fall under the responsibility of the recently created National Biological Survey. At this time no specific plans or schedules have been developed for Galveston Bay. Occasional special studies are performed by USFWS, but these cannot be considered monitoring efforts (B. Cain, USFWS, personal communication).

National Oceanographic and Atmospheric Administration

The NOAA has two programs that involve monitoring activities in Galveston Bay (R. Presley and T. O'Connor, National Oceanic and Atmospheric Administration, personal communication). The first is the Mussel Watch Program, which monitors six stations in Galveston Bay, as shown in Figure 3-3. Oysters are sampled annually for the measurements of trace elements, chlorinated pesticides, polychlorinated biphenyls (PCBs), PAHs, and TBT. Sediments were also sampled during the period from 1986 to 1988. The collected data are stored in a NS&T database in spreadsheet (Excel) or ASCII formats. The cost of the program is $10,000 per site per year or $60,000 per year.

The second NOAA monitoring program is the National Benthic Surveillance Project, which monitors nine sites in Galveston Bay, as shown in Figure 3-3. Fish are sampled from the sites once every two years. Fish tissues are analyzed for organic compounds, chlorinated pesticides, PCBs, PAHs, and pathology of fish livers are measured. Sediments are also sampled for trace metals, organic compounds, pesticides, PCBs, and PAHs. The collected data are stored in a NS&T database in spreadsheet (Excel) or ASCII formats. The cost of the program is $10,000 per site per year or $90,000 per year.

National Marine Fisheries Service

The NMFS has two operational monitoring programs in Galveston Bay. The first is the Brown Shrimp Bait Survey. Bait dealers and fishermen are interviewed, and fishermen logs are reviewed, weekly from April through June to gather catch per unit effort data (i.e., pounds per hour) for juvenile penaeid shrimp. The second program is the Jamaica Beach Program, in which fish and decapod crustacean populations are monitored using drop sampler collections at several salt marsh sites in West Bay near Galveston Island State Park. Sixteen (8 pairs) of vegetated and unvegetated samples were collected monthly from 1982 through 1992. Since 1992, this monitoring program has been scaled back, monthly samples were collected January-July in 1993 and March-May in 1994. Data from these monitoring programs are stored on computer files at the Galveston Lab. No cost or data management information is available for these programs at this time (L. Rozas, NMFS, personal communication).

State Agencies:

Texas Natural Resource Conservation Commission

The TNRCC conducts routine sampling in Galveston Bay to maintain a central database for monitoring water and sediment conditions. The measurements include

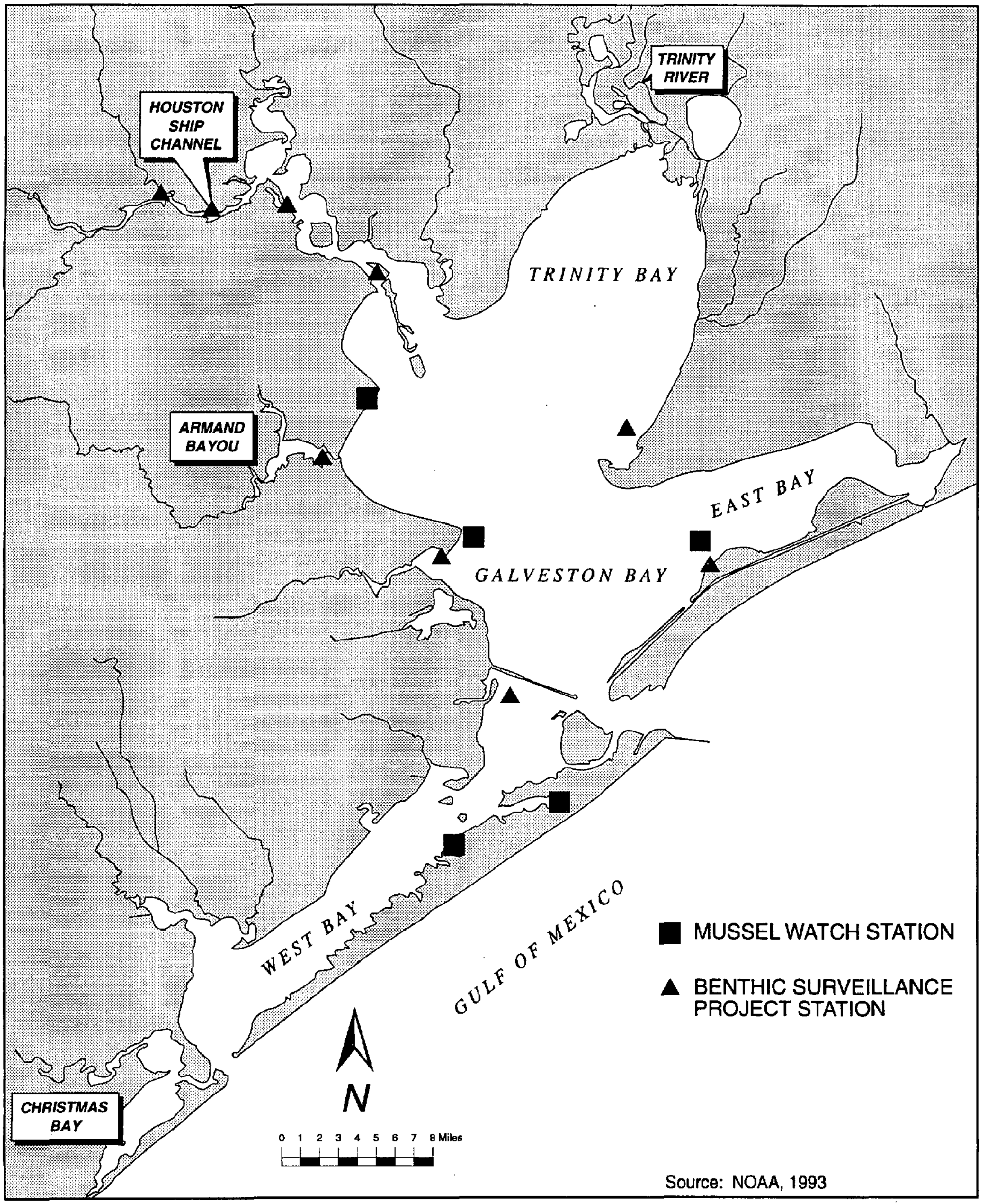


Figure 3-3. National Oceanic and Atmospheric Administration sampling stations in Galveston Bay.

probe, conventional pollutants, nutrients, organics, inorganics, metals toxicity, and tissue (S. Twidwell, Texas Natural Resource Conservation Commission, personal communication). Probe measurements include temperature, dissolved oxygen (DO), conductivity, salinity, and pH. Other conventional water quality measurements include biochemical oxygen demand (BOD) and total suspended solids (TSS). TNRCC measures nutrients such as orthophosphate, nitrite-N, nitrate-N, ammonia-N, and total phosphorus and collects data on fecal coliform bacteria, chlorophyll *a*, and pheophytin *a*. Routine measurements also include total organic carbon (TOC), alkalinity, chloride, sulfate, total dissolved solids (TDS), and volatile suspended solids (VSS).

Additional sampling efforts are conducted less frequently at selected stations. These monitoring efforts include sampling of benthos, nekton, and plankton; and the analyses of metals, pesticides, priority pollutants, inorganics (alkalinity, hardness, and major ions), and toxicity in both water and sediment.

As shown in Figure 3-4, of the 68 stations in Galveston Bay, groups of 55, 10, and 3 stations are sampled four, two and one times per year, respectively. This yields a total of 243 sampling activities per year. For the collection of surface water data, TNRCC field personnel use the procedures and quality assurance practices described in the "Water Quality Monitoring Procedures Manual" (TWC, 1991). The collected data are stored in the Surface Water Quality Monitoring (SWQM) database. TNRCC also maintains self-reporting and compliance monitoring data as part of the INGRES database that contains water quality monitoring data. Based on the total monitoring cost for the entire state and the number of samplings in Galveston Bay, the estimated annual cost for TNRCC's monitoring activities in Galveston Bay was calculated at $112,947. This cost is a proportion of budget line items and may not completely reflect administrative, office, and benefit costs, which are in other budget areas.

Texas Water Development Board

The objective of TWDB's monitoring program in Galveston Bay is to collect data to support calibration of TWDB's models of circulation and salinity, and to support analyses of the relationship between salinity and freshwater inflow (D. Brock, Texas Water Development Board, personal communication). TWDB routinely samples five stations in Galveston Bay (see Figure 3-5). The parameters measured include water temperature, pH, DO, conductivity, and salinity. The measurements are conducted by probes fixed at the sites and are automatically recorded every 90 minutes. The instruments are checked and maintained roughly once a month. The data collected are stored in computers in TWDB in ASCII format but are not transferred to TNRCC's system. The annual cost for the monitoring program is approximated to be $35,000. As with the TNRCC, the estimate reflects line budget items only.

Eight tide gauges are operated in Galveston Bay as part of the Texas Coastal Ocean Observation Network, funded in part by the TWDB, the General land Office, the Texas A&M University at Corpus Christi (TAMUCC) Blucher Institute, and Lamar

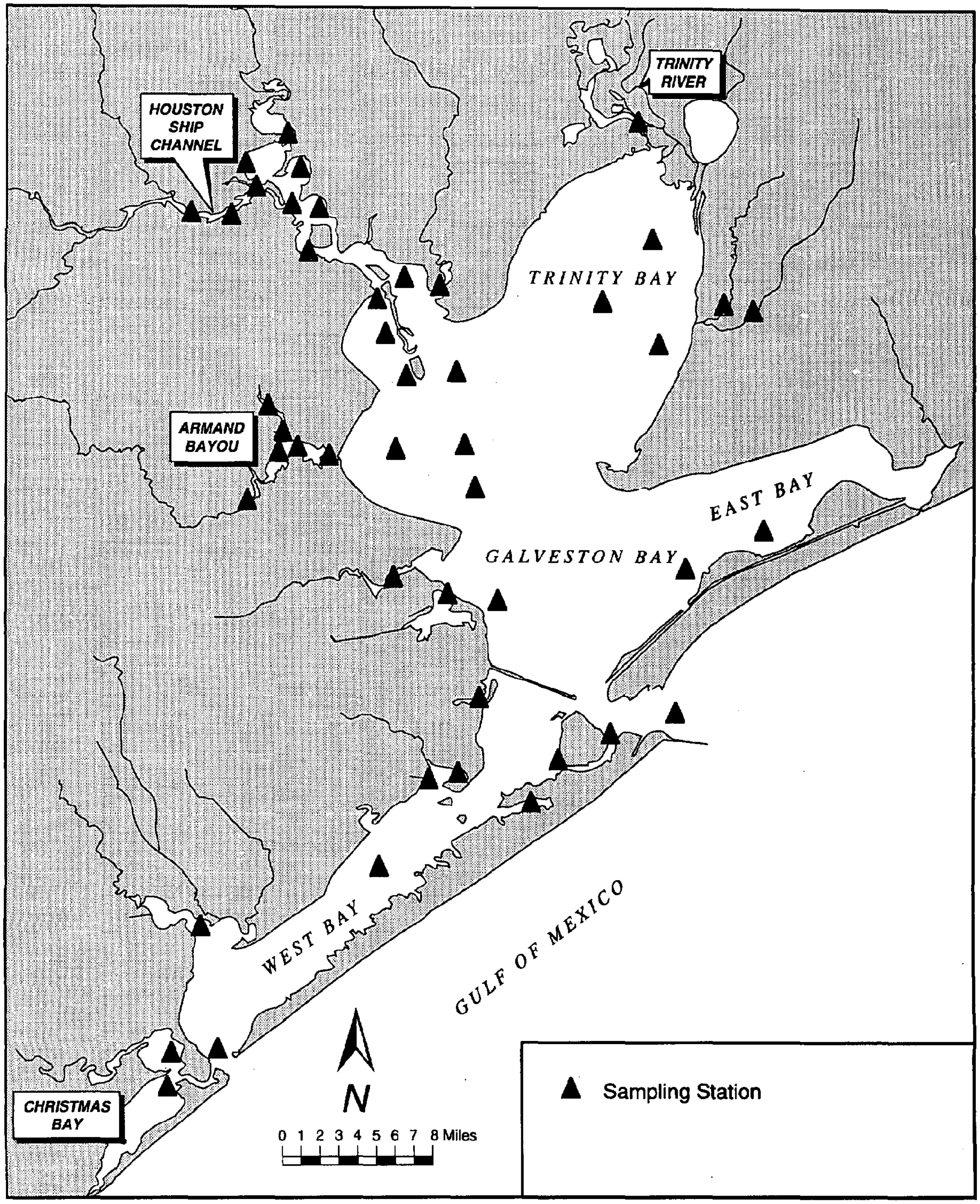


Figure 3-4. Texas Natural Resource Conservation Commission sampling stations in Galveston Bay.

University, in cooperation with NOAA. The locations of these stations are shown on Figure 3-5. Data is inspected by TAMUCC-Blucher Institute staff and all quality assurance procedures (detection of outliers, leveling procedures, documentation, etc.) required by NOAA are also implemented. All raw data collected are stored at TAMUCC. Following data inspection, corrected data is also sent to TWDB for archiving, dissemination, and analysis. Annual costs are estimated to be $50,000 per station.

Texas Department of Health

The objective of TDH's monitoring program in Galveston Bay is to ensure compliance with the National Shellfish Sanitation Program's (NSSP) requirements of using bacteriological monitoring along with pollution source surveys to classify shellfish-producing waters (K. Wiles, Texas Department of Health, Division of Shellfish Sanitation Control, personal communication). The measurements conducted include air and water temperature, tide condition, rainfall, weather conditions, wind direction and velocity, DO, salinity, and fecal coliform bacteria.

TDH routinely monitors 104 stations in Galveston Bay (see Figure 3-6). According to the NSSP guidelines, water samples are collected two feet under the water surface while other parameters are measured by probes. TDH also follows the quality assurance procedures given in the NSSP guidelines. The NSSP guidelines do not require the collection of duplicate water samples. (Duplicate samples are used to assess the consistency of water quality analysis.) The collected data are stored at TDH and not transferred to the SWQM system. An approximated annual cost for the TDH's monitoring activities in Galveston Bay is $80,012. As with the TNRCC, this cost is a proportion of budget line items and may not completely reflect administrative, office, and benefit costs, which are in other budget areas.

Texas Parks and Wildlife Department

The TPWD has undertaken three monitoring programs in Galveston Bay. The first is the Resource Monitoring Program. Gill nets are set during two 10 week seasons, spring and fall with 45 nets set during each season. On a monthly basis 20 trawl, 30 oyster dredge, and 20 bag seine samples are collected in Galveston Bay. Six trawl samples are collected in the Gulf Intracoastal Waterway (GIWW) and six bag seine, six beach seine, and 16 trawl samples at offshore sites (Galveston jetties to Freeport jetties). The sampling is conducted on a monthly basis except for the gill nets, which are done in the spring and fall only. The exact sampling sites are selected randomly each month from a grid system. Weather conditions, tide conditions, temperature, salinity, DO, and turbidity are measured when collecting samples. The collected samples are analyzed for species identification, counts, size, weights (occasionally), sex, and maturity. Large, live fishes are tagged to allow growth and mortality estimates and to monitor movement (L. Robinson, TPWD, personal communication).

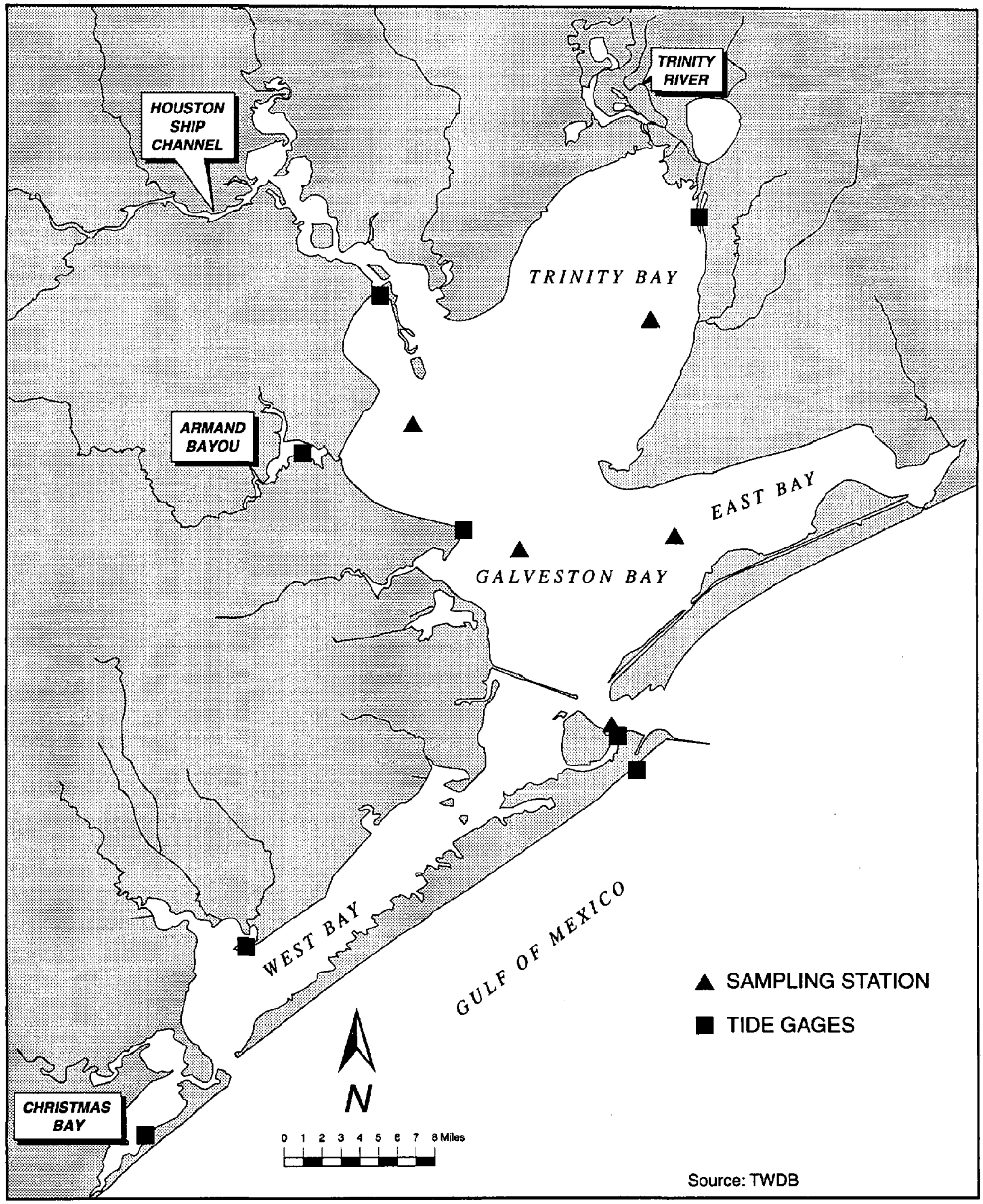


Figure 3-5. Texas Water Development Board sampling stations in Galveston Bay.

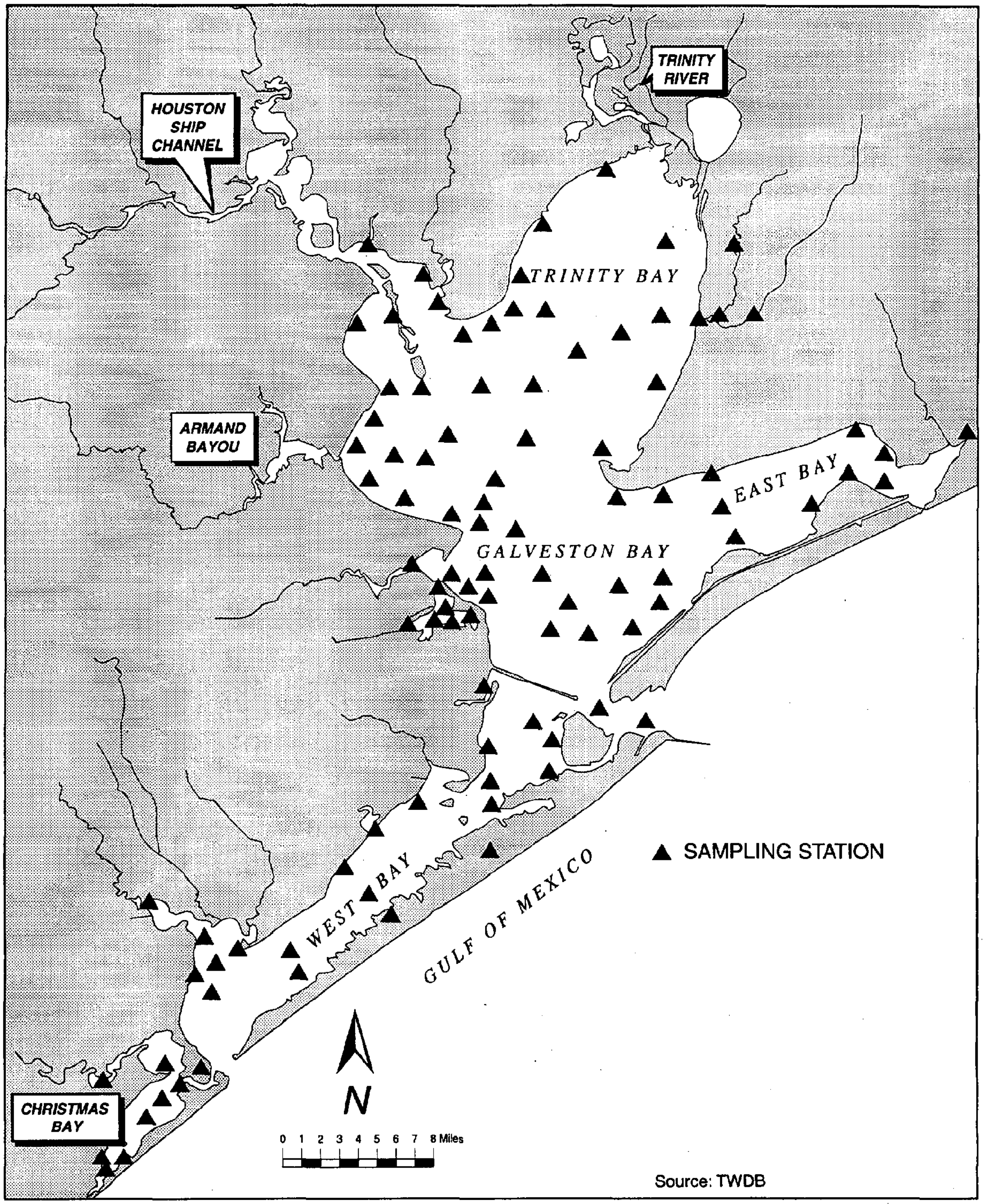


Figure 3-6. Texas Department of Health sampling stations in Galveston Bay.

Oyster monitoring, previously carried out at random open-bay bottom sites and on defined oyster reef areas, has been reduced to oyster reefs only. Monthly sampling is based on counting the live organisms collected from a series of 30-second oyster dredge trawls. Counts of oyster spat, encrusting organisms, and the percentage of live and dead oysters are also recorded. Standing crop estimates are made from the number of organisms collected on a per-effort basis. This data is used in conjunction with the Texas Department of Health's National Shellfish Sanitation Program efforts for the regulatory control of harvest season duration and harvesting areas. The data for all monitoring are stored in a mainframe computer in Austin, Texas, and are SAS or ASCII retrievable. Quality assurance and quality control are specified in operations manuals issued by TPWD and are applied to all coastal resource sampling programs. This includes inspection trips by supervising biologists and managers to evaluate consistency. Ecosystem leaders from other field systems will also accompany field crews to monitor for consistency between field stations. The annual monitoring cost for this program is estimated from labor (eight personnel involved) and supporting costs to be $250,000.

The second monitoring program is the Coastal Resource Harvest Commercial Landings Program (L. McEachron, P. Campbell, and L. Robinson, Texas Parks and Wildlife Department, personal communication). Ninety-five seafood dealers are interviewed monthly for information about all commercial finfish, shrimp, crab, oyster, and other marine life. The licensed dealers are required to report all edible saltwater products purchased from commercial fishermen through the submission of *Monthly Aquatic Products Reports* to TPWD or NMFS. The parameters collected include total weight of catch (or number of individuals), price per pound, and the name of the water body where seafood is collected. Quality assurance includes cross-checking data and following the Procedures Manual. The data are stored in a mainframe computer in Austin on magnetic tape. The cost of the program is about $10,000 plus labor costs for two personnel, resulting in an estimated total of $60,000.

The third monitoring program is the Coastal Resource Harvest Recreational Landings Program (L. Robinson, L. Green, and L. McEachron, Texas Parks and Wildlife Department, personal communication). This program involves conducting on-site, trip-end interviews on 125 boat access survey sites. Thirty-one weekend and 66 weekday interviews are conducted from May 15 to November 20, and 12 weekend and 24 weekday interviews are conducted from November 21 to May 14, respectively, totaling 133 surveys per year. The information gathered includes boat registration number, time of interview, trip length, number of people in the party and their residence, area fished, gear, bait and amount, fish landed by species, total lengths of fish (six per species), grade for trip success, species sought, amount of live bait (shrimp, mullet), and methods of obtaining baits (caught or bought). Quality assurance/quality control includes interviewer's observations, inspection trips by supervising biologists and managers to ensure consistency, editing and cross-checking data input, and following the Operation Manual procedures. Interview data sheets are kept on file for future reference. Currently, the collected data are stored in a mainframe computer in Austin on magnetic tape. This is being converted to a disc-based M204 database. The monitoring cost is $110,000 plus labor costs for three personnel, resulting in an estimated total of $200,000.

Local Agencies:

City of Houston

Two departments in the City of Houston conduct routine monitoring of tidal tributaries to Galveston Bay. The first is the Department of Public Works and Engineering (DPW&E), Wastewater Operations, which monitors the major bayous in the vicinity of Houston. The objectives of the monitoring program are to resolve concerns over water quality conditions in the bayous and to aid in locating and correcting sewer leaks (T. Glanton, City of Houston, Department of Public Works and Engineering, Wastewater Quality Control, personal communication).

DPW&E monitors 45 stations in the tidal and non-tidal portions of major bayous (see Figure 3-7). Most of them are sampled once per week but in winter or under high flows the frequency may be reduced to once per month. DPW&E monitors parameters such as DO, temperature, pH, ammonia-N, nitrate-N, BOD, TSS, conductivity, and FC. The measurements and QA procedures are based on EPA approved guidelines. Data collected by DPW&E are stored in the department but are not transferred to the SWQM system. The annual monitoring cost is approximately $100,000. This estimate is based on personnel involved and includes estimated overhead costs.

Additionally, the Health and Human Services Department (HHSD), Bureau of Public Health Engineering, has two groups conducting monitoring. The Field Operations Unit monitors 54 stream stations in the Houston area as well as all permitted wastewater dischargers. The stream stations are monitored on a roughly monthly basis for conventional parameters and nutrients. Although this monitoring effort is a significant one, the 54 stations are essentially all above tidal waters and are not included as part of this monitoring effort. The data collected are stored in a city computer database and are provided to the TNRCC (Austin and Region 12) in paper and machine readable forms (T. Fisher, City of Houston, Health and Human Services Department, Bureau of Public Health Engineering, Field Operations Unit, personal communication).

The Quality Assurance Group of the Bureau of Public Health Engineering of HHSD also monitors a number of stations (D. Krentz, City of Houston, Health and Human Services Department, Bureau of Public Health Engineering, Quality Assurance Group, personal communication). Although most of its stations are in Lake Houston and its watershed, part of the monitoring effort is in six major Houston bayous.

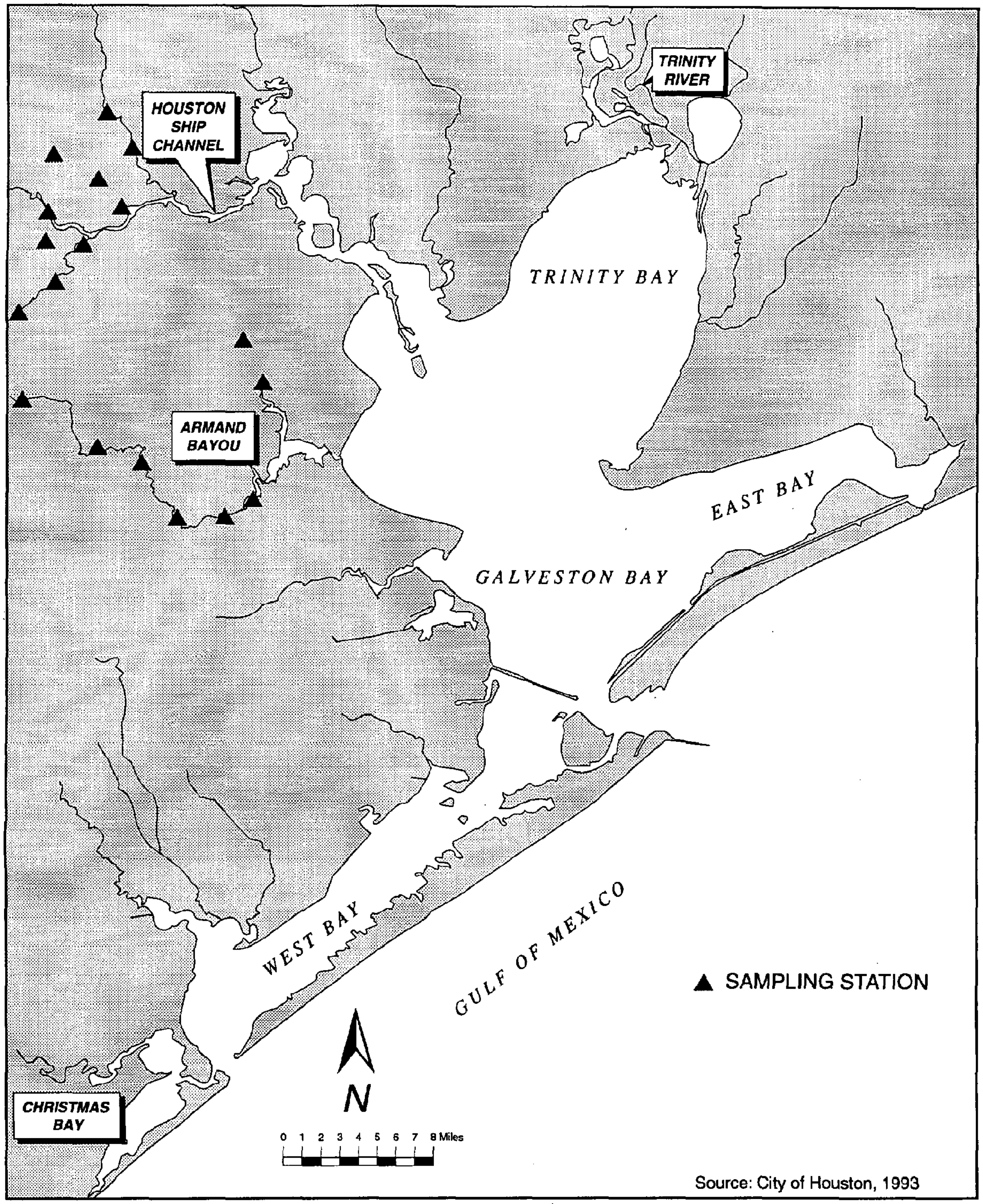


Figure 3-7. City of Houston Department of Public Works and Engineering sampling stations in tidal and near tidal portions of Galveston Bay.

These stations are all at USGS monitoring stations and include the lowest USGS station on each bayou. Figure 3-8 shows the stations that are in or near tidal waters. These stations are monitored two to four times per month for conventional parameters as well as nutrients, organics, and inorganics. In addition, metals are measured non-routinely. The collected data are stored on a DB-4 (FoxPro) database and are available to the TNRCC. However, they are currently not part of the SWQM system.

<u>Harris County Pollution Control Department</u>
The Harris County Pollution Control Department (HCPCD) monitors nine stations on the Houston Ship Channel (HSC) and six stations on the San Jacinto River below Lake Houston, as shown in Figure 3-9. These 15 stations are monitored once per month for conventional parameters as well as nutrients, organics, inorganics, and selected total metals. In addition, HCPCD monitors each of the industrial dischargers in the county every two to eight weeks for applicable permit parameters; the frequency of sampling of a facility is based on the historical quality of its discharge. Each municipal discharge is monitored every two months for applicable permit parameters with the exception of facilities judged to have poor quality discharges. These facilities are monitored weekly. Violation notices for exceedences are issued and compliance, voluntary or through legal action, as necessary, is sought. HCPCD also maintains an extensive program to eliminate illegal discharges and illicit connections to the County drainage system. The collected samples are analyzed by the county laboratory and stored on an IBM System 36 computer and in paper form. Data have been collected since the early 1970s, but a fire in 1980 may have destroyed the earlier records. Annual costs for point source monitoring is approximately $400,000 and ambient monitoring expenditures are approximately $20,000 (N. Tyer, HCPCD, personal communication).

<u>Galveston County Health District</u>
The Galveston County Health District (GCHD) Pollution Control Department, has been collecting data in Galveston Bay since 1972, as mandated by SB 835. GCPCD monitors 92 stations (see Figure 3-10), including beach and bay side of Galveston Island and most of its bayous, for probe, conventional pollutants, nutrients, and weather conditions. At GCPCD, 2.5 people currently work in field operations and one person does laboratory work. The collected data are on paper only.

Most GCPCD stations are monitored monthly, with permitted dischargers being monitored one to three times per year. The monitoring costs are estimated to be about $200,000 per year with a majority of the effort devoted to point source monitoring (G. Fogarty, GCHD, personal communication).

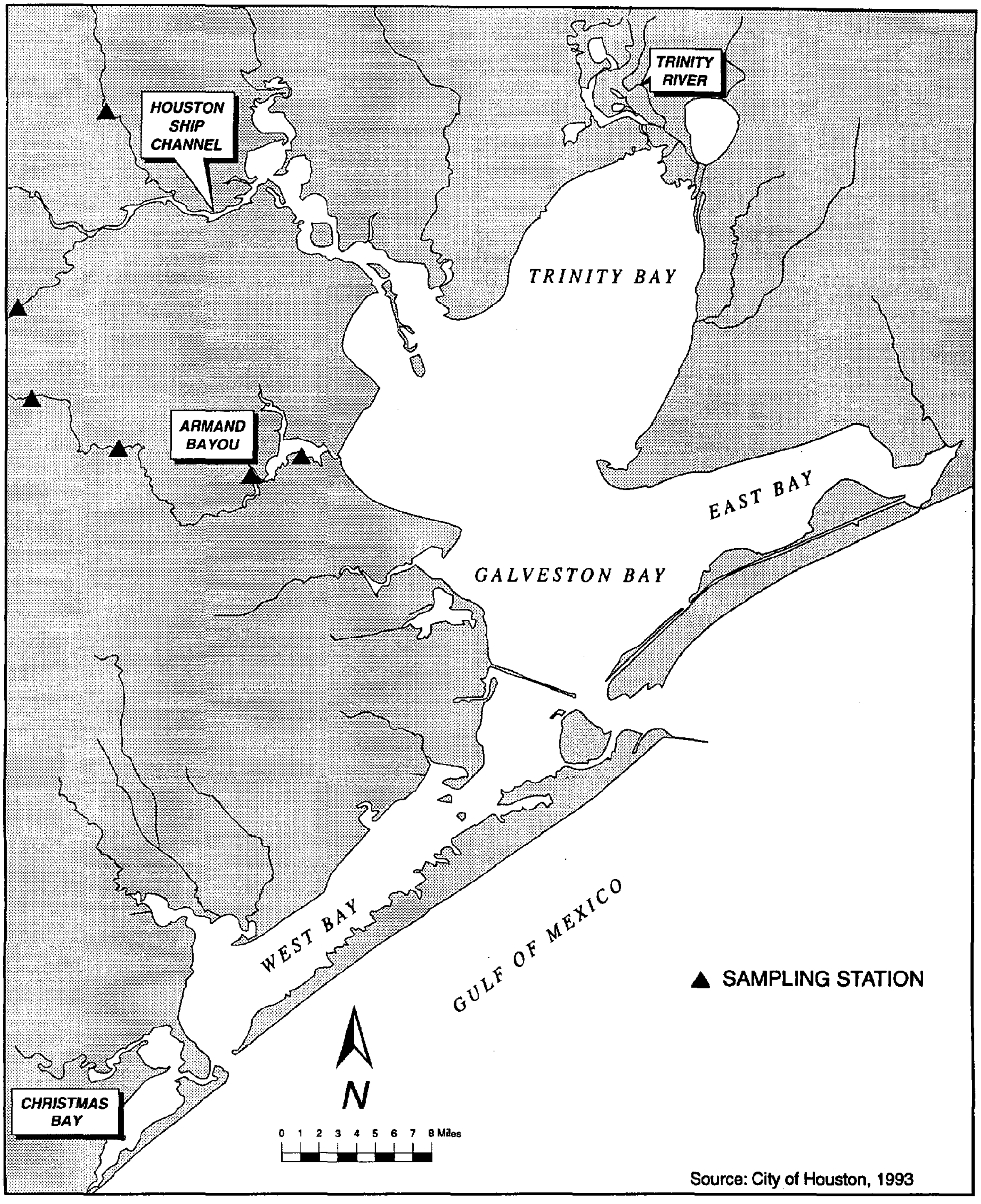


Figure 3-8. City of Houston Health and Human Services Department sampling stations in Galveston Bay.

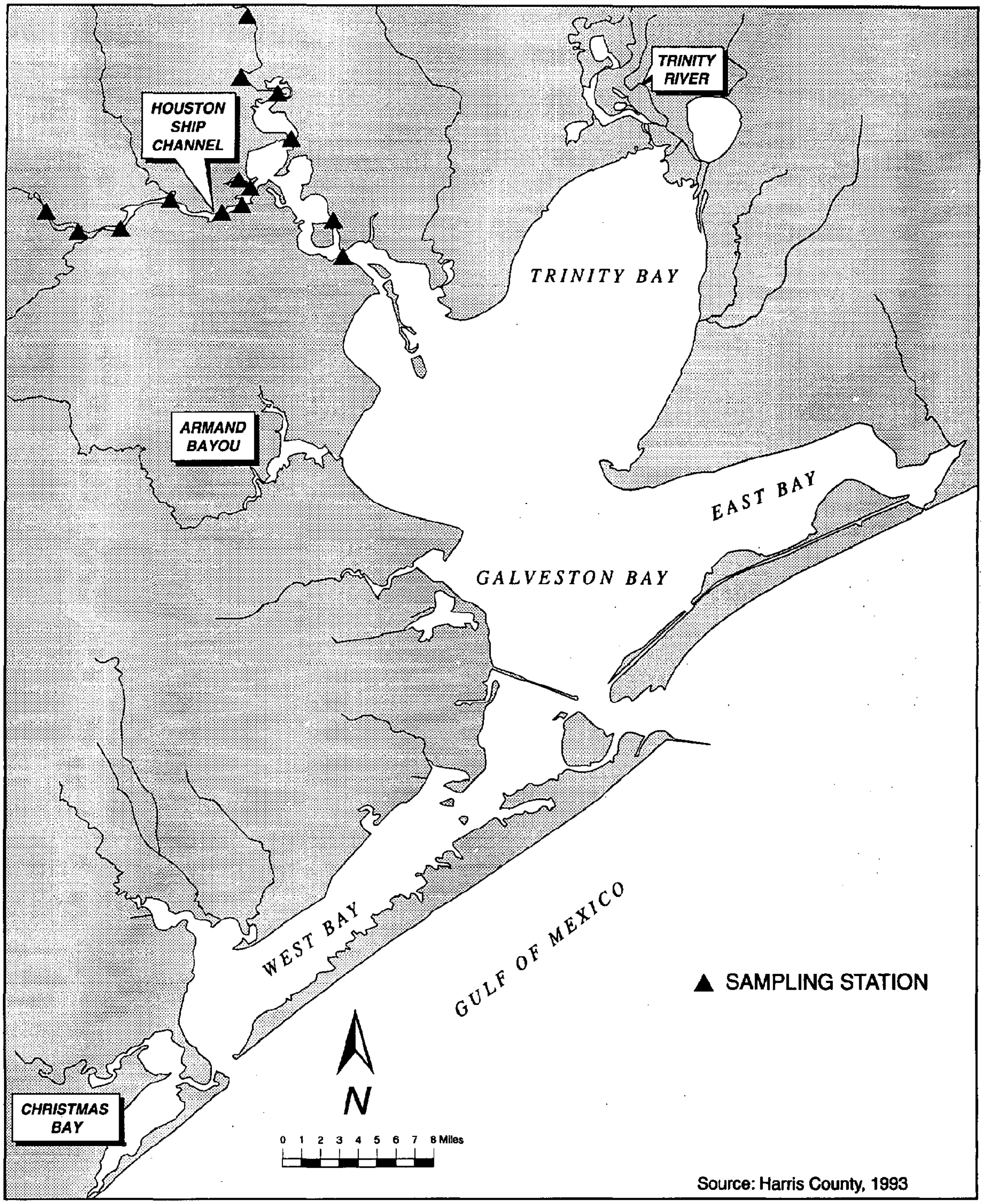


Figure 3-9. Harris County Pollution Control Department sampling stations in Galveston Bay.

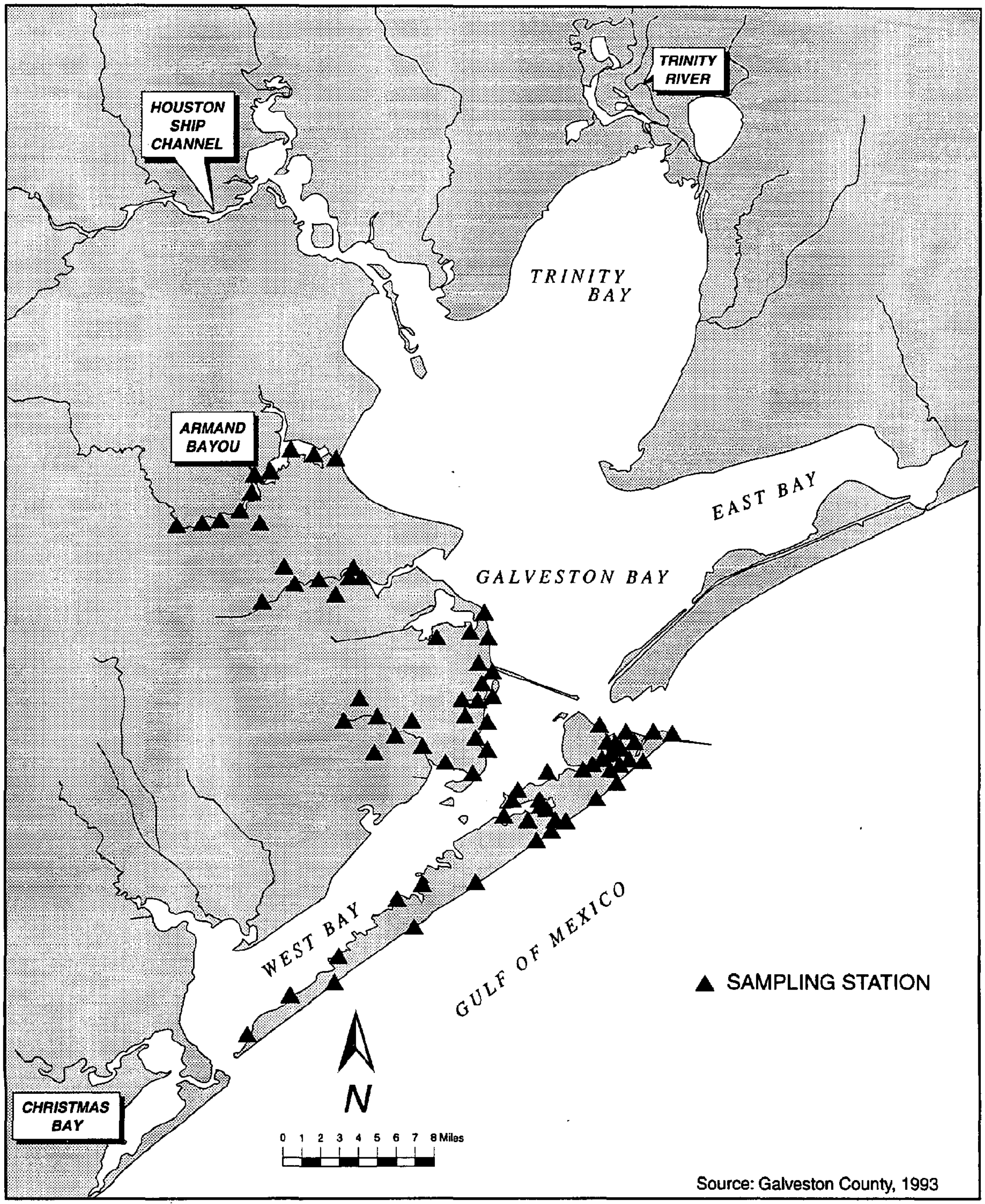


Figure 3-10. Galveston County Health District Pollution Control sampling stations in Galveston Bay.

Citizen's Monitoring Programs

Interest in citizen's monitoring programs has increased significantly over the past several years and is one of the actions detailed in *The Galveston Bay Plan* (Action PPE-6). The TNRCC, through the Texas Watch program, has supported environmental monitoring by local citizen's groups to supplement existing monitoring programs. For example, the Galveston Bay Foundation (GBF) coordinates a volunteer monitoring network called The Estuarine Sampling Team (TEST). Numerous other citizen monitoring groups also are active in the Galveston Bay watershed, mostly in the upper bayou areas of Houston.

GBF works under the umbrella of Texas Watch, a division of the Texas Natural Resource Conservation Commission. There are currently 34 stations in the GBF TEST network (Figure 3-11). GBF TEST coordinates as much as possible with local and state monitoring agencies with regards to site selection. All stations are sampled at least two times a month, with most being sampled weekly. These volunteers are trained to collect key water quality data, such as dissolved oxygen, pH, temperature, salinity/conductivity, water clarity and to record information on general site conditions. The monitors use EPA-approved protocols which are detailed in the Texas Watch Quality Assurance Project Plan (TNRCC, 1992). The data is provided to Texas Watch for inclusion in the TNRCC database. The information is used to support and enhance professional data by providing expanded spatial and temporal coverage (C. Fitzgerald, Galveston Bay Foundation, personal communication).

Participation by volunteer monitoring groups is also evident in several surveys conducted to evaluate Galveston Bay bird populations. The Texas Colonial Waterbird Society and the TPWD jointly participate in the Texas Colonial Waterbird Survey (TCWS). Results of this survey have been compiled and published from 1973 to the present. Surveys are conducted annually during a two-week period beginning the last of May, corresponding to the incubation period of most colonial nesting waterbirds. The Christmas Bird Count (CBC) is sponsored by the National Audubon Society. This a less rigorous survey of day-long tallies of birds seen within four 24-km diameter areas.

Monitoring Summary

There are 19 programs presently conducting monitoring in Galveston Bay. The collected data are, in most cases, stored on in-house computers under any of a variety of formats or on paper. Although most data are made available to the public, access is often difficult. There is no central data storage system that would allow easier access for the public or the agencies presently concerned with monitoring Galveston Bay. Some duplication of effort is noted, particularly for point source monitoring. Data management efforts were directed at fulfilling specific agency mandates.

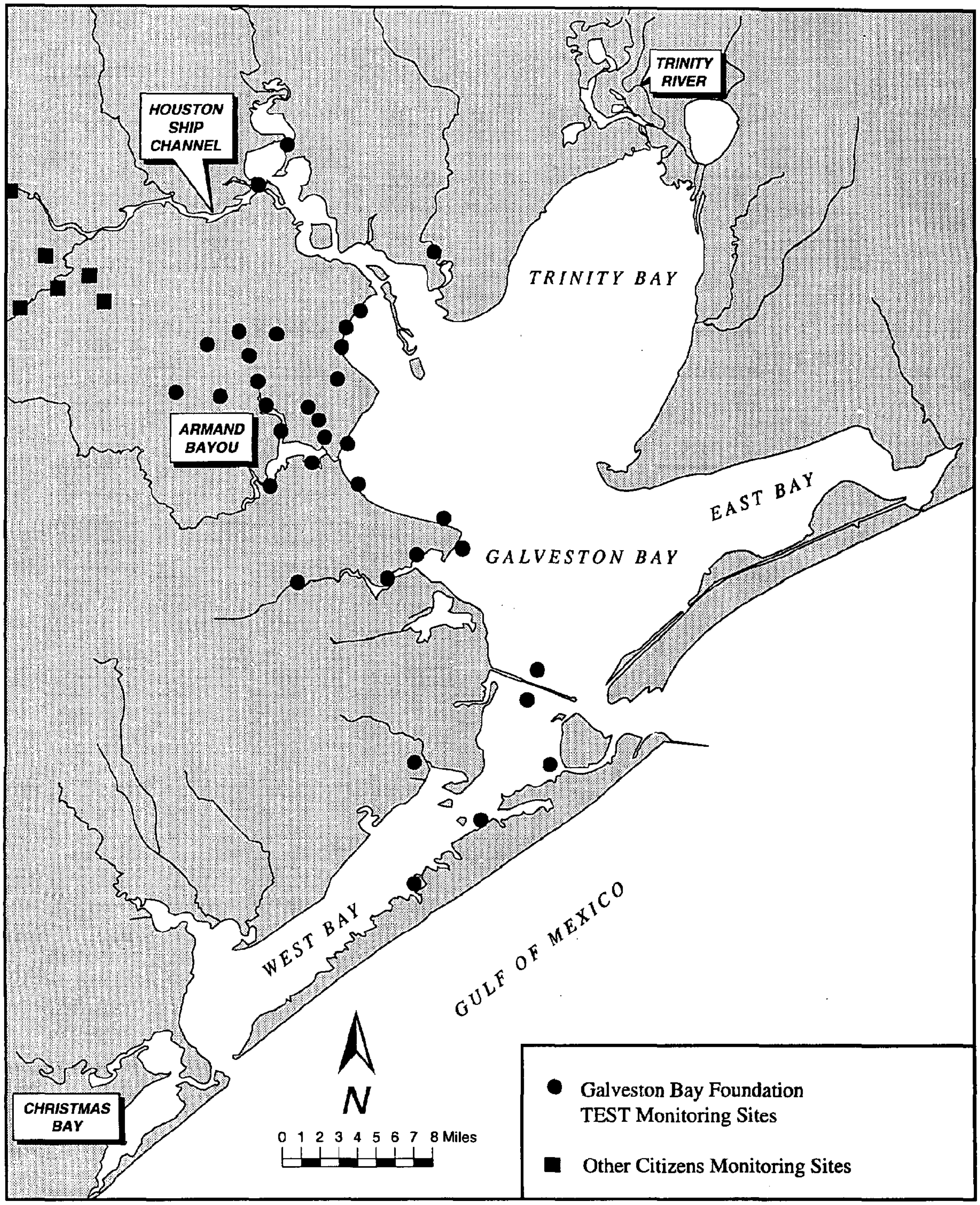


Figure 3-11. Citizens monitoring sites within the Galveston Bay watershed.

Figures 3-12 and 3-13 summarize the geographic and temporal coverage, duration, level of detail, and data quality assurance for physical/chemical and biological monitoring programs, respectively. The completeness of the circle in each cell

indicates the extent to which that study area has been addressed in existing monitoring programs. The terms "Higher" and "Lower" quality indicate whether the existing data are sufficient to provide system-wide insights to the study area or processes indicated — they are not intended as judgments of the statistical or laboratory quality of the data.

Figure 3-12 shows that an emphasis exists on collecting physical and chemical data at point sources, with moderate coverage of sediments and conventional water quality parameters. Among the greatest weaknesses are the lack of:

- Long-term fish and shellfish tissue monitoring,
- Wide spread sediment monitoring information,
- Standardized monitoring methods, and
- Temporal and spatial coordination among monitoring efforts.

The lack of coordination in monitoring efforts has resulted in the inability to conduct valid correlation and multivariate analyses.

Figure 3-14 summarizes physical/chemical and biological information emphasized by individual monitoring programs. In this figure, the level of emphasis is indicated by the completeness of the circle and the quality of the data by shading. As in the previous two tables, data quality is assessed based on the ability to provide sufficient insight for making management decisions and is not intended as a judgment of statistical or laboratory quality. Figure 3-14 shows that although there is good overall coverage, individual programs tend to be highly focused. This underscores the need to integrate monitoring efforts as a means of optimizing the value of collected information.

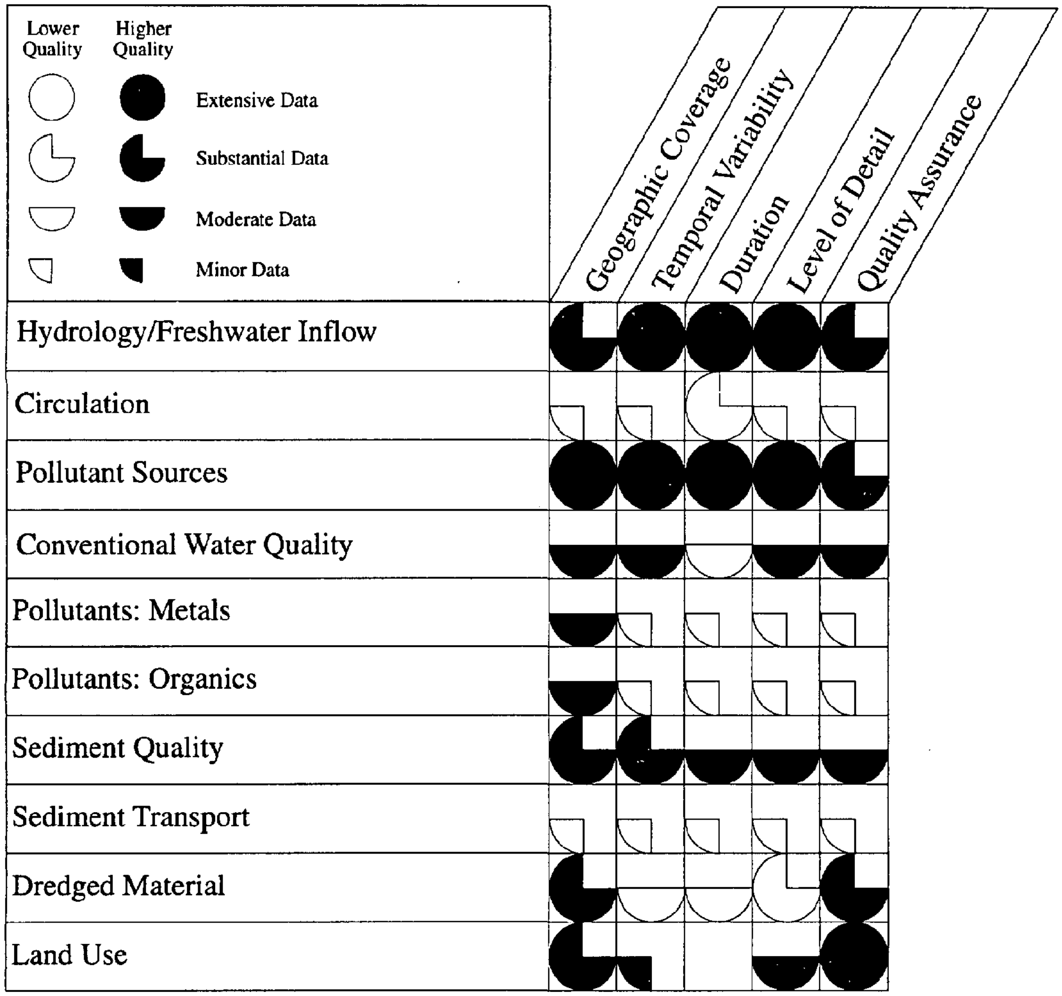
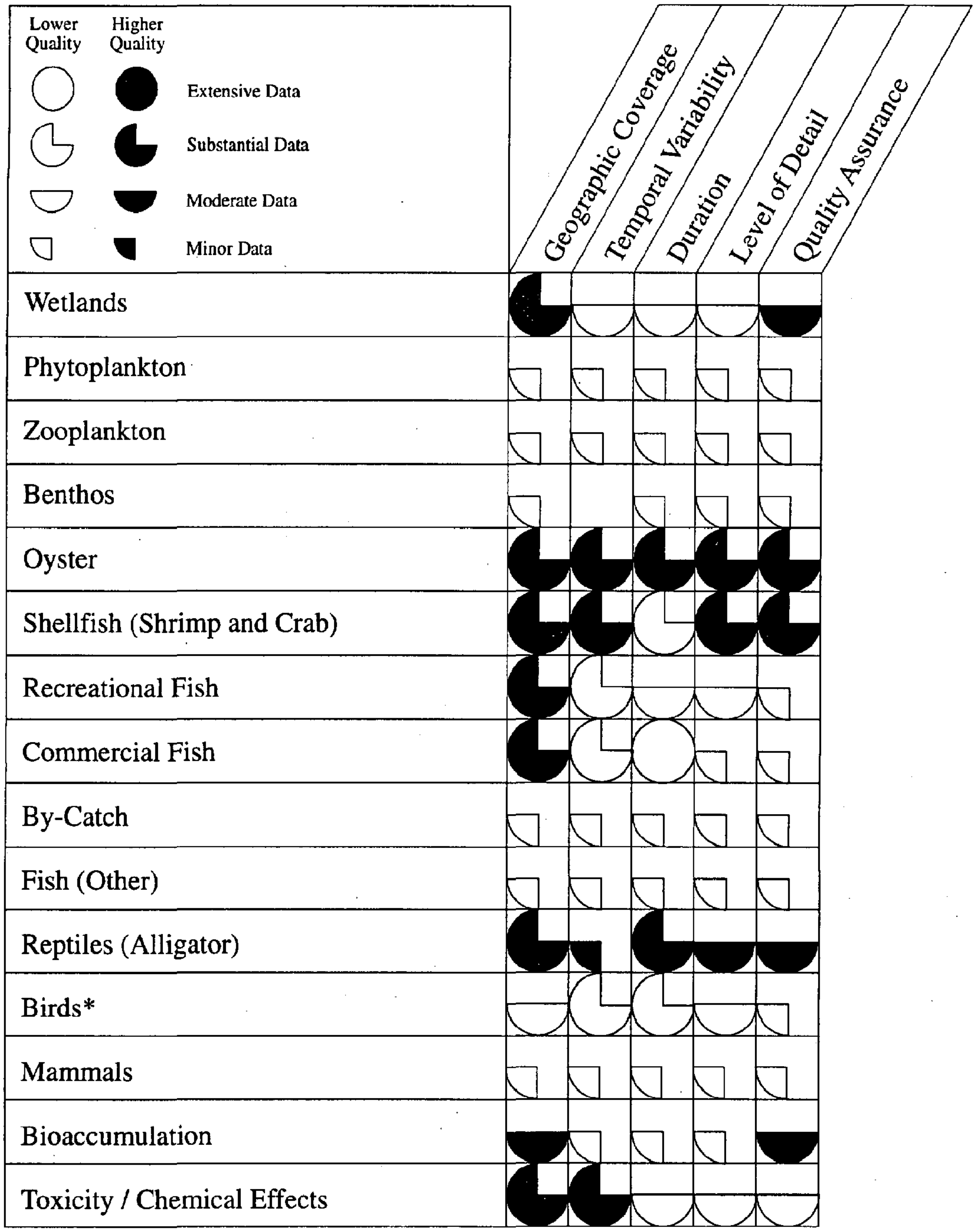


Figure 3-12. Summary of physical and chemical information on Galveston Bay.

* "Higher" and "Lower" quality indicate whether the existing data are sufficient to provide system-wide insights to the study area or processes indicated — they are not intended as judgments of the statistical or laboratory quality of the data.



* Provided by National Audubon Society Christmas Bird Count Program

Figure 3-13. Summary of biological and ecological information on Galveston Bay provided by monitoring programs.

* "Higher" and "Lower" quality indicate whether the existing data are sufficient to provide system-wide insights to the study area or processes indicated — they are not intended as judgments of the statistical or laboratory quality of the data.

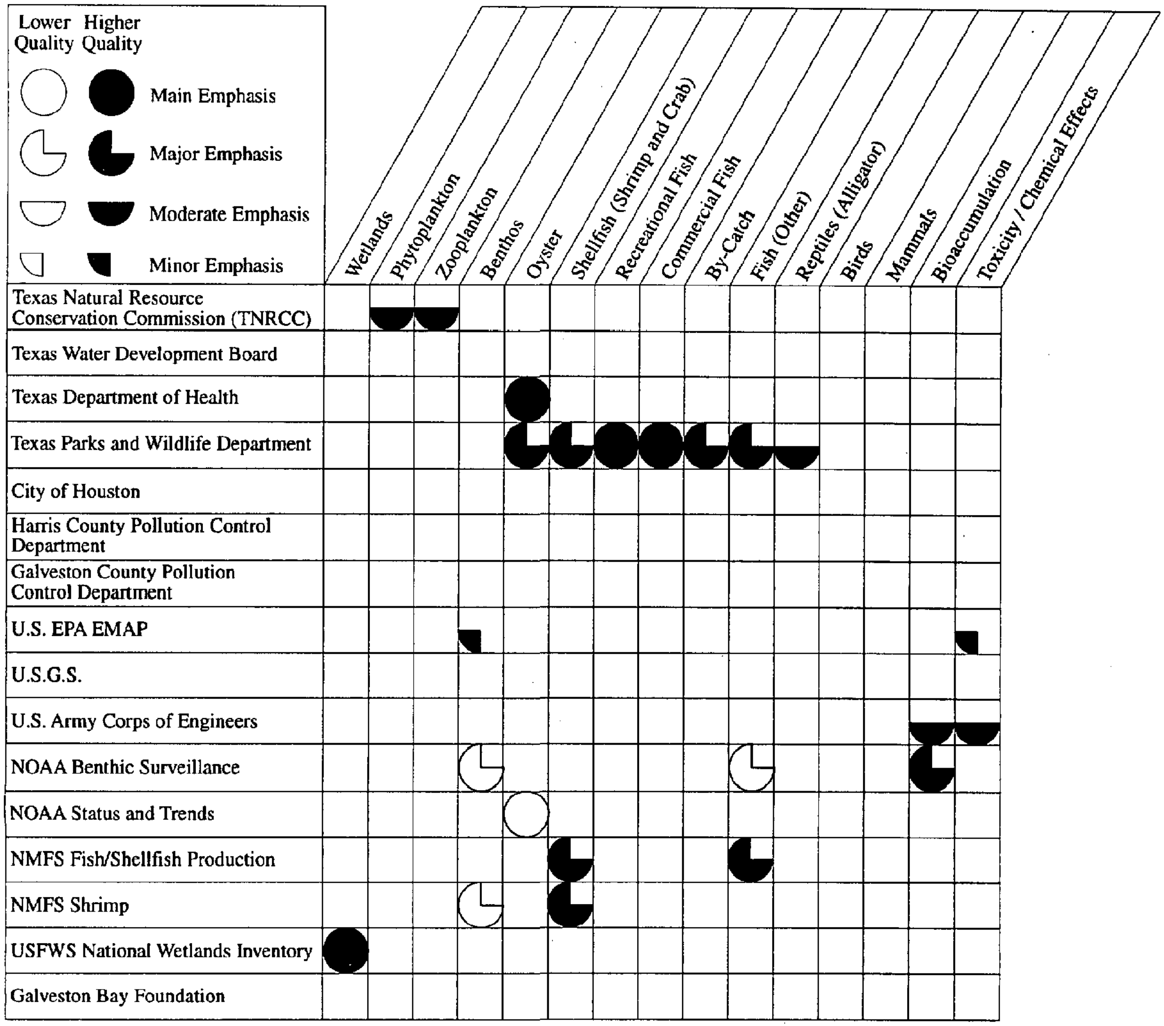


Figure 3-14. Summary of physical/chemical and biological information supplied by monitoring programs.

* "Higher" and "Lower" quality indicate whether the existing data are sufficient to provide system-wide insights to the study area or processes indicated — they are not intended as judgments of the statistical or laboratory quality of the data.

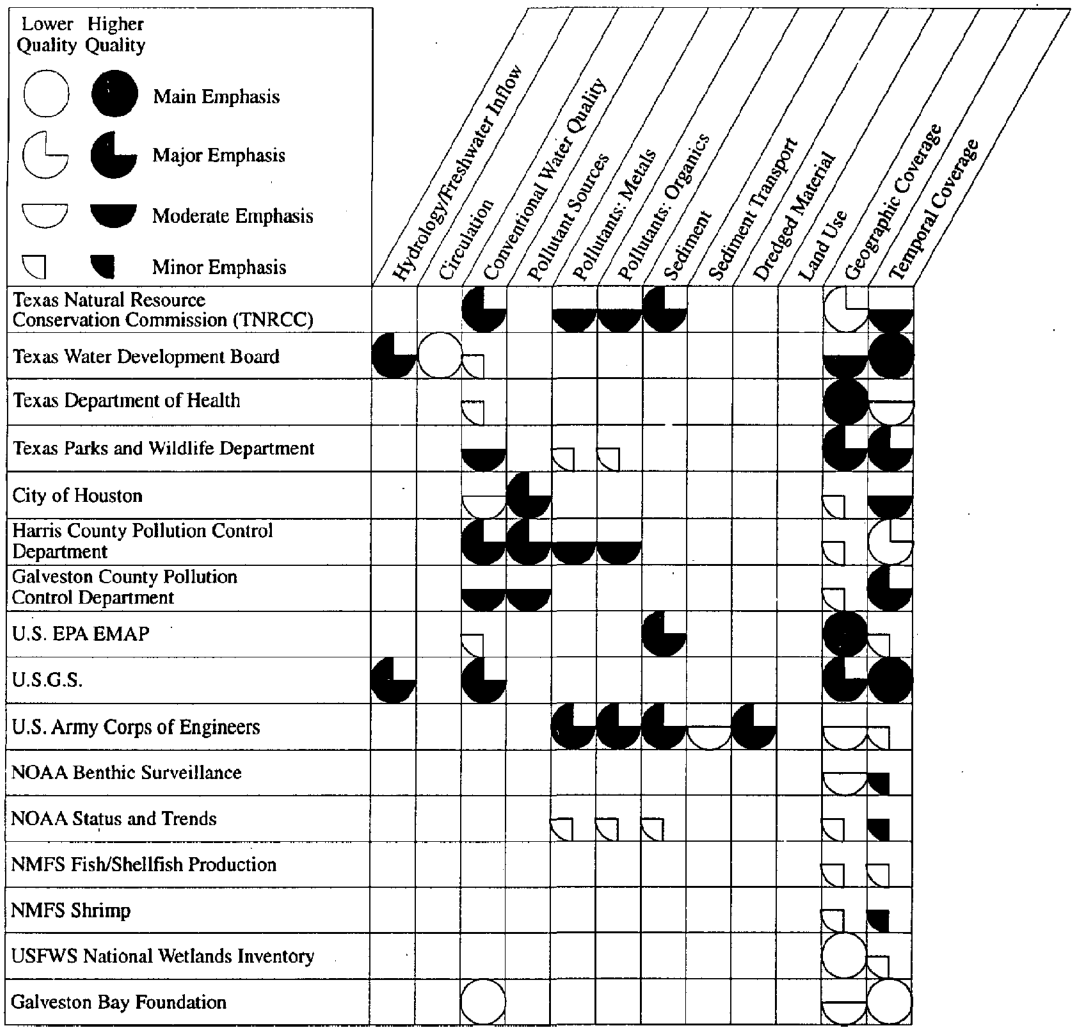


Figure 3-14. Summary of physical/chemical and biological information supplied by monitoring programs. (cont'd).

* "Higher" and "Lower" quality indicate whether the existing data are sufficient to provide system-wide insights to the study area or processes indicated — they are not intended as judgments of the statistical or laboratory quality of the data.

Chapter 4

Habitat Protection

Priority Problem

The Galveston Bay Estuary is composed of a variety of aquatic habitats ranging from open water areas to coastal wetlands. Maintaining varied and abundant high-quality habitat helps ensure the health and biological diversity of the entire estuarine system. Wetlands serve important hydrological, biological, and ecological functions in the bay ecosystem. Ensuring the protection of habitats in the Galveston Bay estuary has been designated as the most critical of all of the problems facing the bay.

Land cover change may be seen as an indicator of increases or decreases in water quality. Increases in developed land displacing wetland habitat, may result in land disturbance which increases erosion and sedimentation and by hydrologic alterations which increase runoff. Concomitant loss of the pollution mitigating properties of such wetland habitats impacts water quality as well. Landcover change is directly linked to habitat quantity and indirectly to habitat quality.

A trend of wetland decline has been identified within the estuary, threatening the sustainable productivity of the bay. This problem has been identified as the most critical of all problems currently facing the bay. Wetlands decline has been attributed to five major causes: 1) man-induced subsidence; 2) erosion; 3) direct conversion for agricultural, urban, industry, and transportation purposes; 4) dredge-and-fill activities; and 5) projects in which wetland areas are artificially isolated from the bay.

Management Goals and Objectives

Management goals are directed at reversing the decline of critical habitats and addressing high rates of erosion along bay shorelines. The stated goals of the Habitat Protection Action Plan are to:

- Expand areas and restore quality of wetland habitats,
- Halt the conversion of wetlands to other uses,
- Acquire existing wetlands and encourage conservation,
- Restore and create colonial nesting bird habitat, and
- Selectively moderate erosional impacts.

To achieve these goals the following specific objectives were adopted:

Objective 1	Create or restore 15,000 acres of vegetated wetlands within 10 years.
Action HP-1	Restore, create and protect wetlands.
Action HP-2	Promote beneficial uses of dredged material to restore and create wetlands.
Objective 2	Restore natural functions and values to 50% of degraded wetlands within 20 years.
Action HP-3	Inventory degraded wetlands and fund remedial measures.
Objective 3	Sustain no net loss of existing wetlands.
Action HP-4	Implement a coordinated, system-wide wetland regulatory strategy.
Objective 4	Place 50,000 acres of wetland habitat in public ownership within 20 years.
Action HP-5	Acquire and protect quality wetlands.
Objective 5	Develop economic incentives to encourage owners to protect wetlands from development.
Action HP-6	Develop economic and tax incentive programs to protect wetlands.
Objective 6	Improve and protect the habitat on 10 major colonial bird nesting sites within 5 years.
Action HP-7	Facilitate bird nesting on existing islands.
Objective 7	Create 2 additional bird nesting islands within 10 years.
Action HP-8	Build nesting islands using dredged materials.
Objective 8	Adopt a coordinated ecosystem approach to reduce erosional impacts to the bay.
Action HP-9	Reduce erosional impacts on wetlands and habitats.

Data Information Needs

The goal of Plan Objectives 1, 2, 3, 4, 6, 7, and 8 is to reverse the decline in the areal extent of wetlands, colonial nesting bird habitat, and other habitats of concern in the Bay. Information needed to assess these management objectives include:

- Identification of habitats of concern,
- Status and trends in areal extent and distribution of existing habitats of concern,
- Status and trends in areal extent and distribution of habitats created and restored by special projects, and
- Habitat change analysis information on a usable frequency.

The status of the areal extent and distribution of identified habitats of concern provides information needed to infer the ability of existing habitats to provide suitable habitat for bay biota, to moderate hydrological processes, to provide organic carbon to the estuarine food web, and to maintain water quality. Habitat data may also be used to evaluate the strength of the relationship between the areal extent of a habitat and the abundance of resident species. Trend information provides a means for evaluating whether progress is being made toward meeting Plan Objectives 1, 3, 5, 6, and 7.

Because it is not feasible to measure all environmental parameters, a set of primary indicator parameters were identified for the habitat component of the regional monitoring program. Primary habitats of concern in Galveston Bay have been identified by Task Force members (Table 4-1). The designation of indicator habitats does not mean that information on other habitats will not be collected, only that these have been selected as habitats of primary concern. These recommendations were made utilizing information from interviews with habitat experts from government agencies, academic institutions, and other local organizations.

The goal of Plan Objective 2 is to restore the quality of wetland habitats. Information needed to assess this management objective include:

- Identification of indicator parameters for habitat quality,
- Status and trends in the quality of existing habitats of concern, and
- Status and trends in the quality of degraded wetland habitats.

The status of habitat quality provides a means for assessing whether existing, restored, and created habitats are of adequate quality to support desired functions and values. These data may also be used to evaluate the strength of the relationship between habitat quality and the abundance of resident species. Trend data provides a means for evaluating whether progress is being made toward improving the quality of habitats throughout the estuary.

A primary purpose of Plan Objectives 1 through 8 is to ensure that there will be habitats of adequate quantity and quality to maintain and enhance Bay species. Many marine finfish and shellfish depend on these habitats during all or part of their life history. Continued loss of these wetland habitats may lead to the collapse of coastal ecosystems and their associated fisheries. Change (increases or decreases in areal extent, movement, consolidation or fragmentation, or qualitative change) in

TABLE 4-1. CANDIDATE INDICATORS AND MEASUREMENTS FOR HABITAT PROTECTION

Indicator Habitats	Measurement
Marsh	
•All marsh types	Areal extent and distribution
	% emergent vegetation
	% open water dominated by aquatic vegetation
	Marsh edge and interspersion
	Water duration
	Open water depth
	Salinity
	Aquatic organism access
•Brackish marsh	Change in relative sea level - subsidence/erosion
•Salt marsh	Percent *Spartina alterniflora*
Submerged vegetation	Areal extent and distribution
•Sea grasses	Biomass
	Vegetation spp. composition
	PAR
	Salinity
Oyster reefs	Areal extent and distribution
Colonial waterbird nesting habitat	Number of colonies and distribution
	# nesting pairs
	Abundance of predators (e.g., raccoons)
	Elevation above sea level
	Accessible feeding habitat
	Connectivity to mainland
	Indications of human disturbance

submerged and wetland habitat may be a sensitive integrator of overall water quality and potential for change in fisheries productivity. The task of identifying animal species that depend on wetlands for their existence was given to the Species Population Protection Task Force. Information on the status and trends in abundance and distribution of species whose existence depends on identified habitats of concern (see Chapter 5: Species Population Protection) is required to assess habitats are having the desired effect on animal populations they support. Habitat change data may be compared to species abundance trend data to evaluate the strength of the relationship between the areal extent and quality of a habitat to abundance of resident species.

Monitoring activities must provide information to evaluate whether progress toward these management objectives is being made. The habitat protection component of the regional monitoring program must provide data to assist in:

- Determining whether severe alterations to important habitats are occurring,
- Identifying potential causes of alterations in habitats and the species they support,
- Evaluating alternative actions to mitigate identified adverse impacts to habitats and the species they support.

The following monitoring objectives have been used to design the regional monitoring program for Galveston Bay:

- Determine trends in the areal extent and distribution of selected habitats of concern,
- Determine the extent of habitat continuity and fragmentation,
- Determine trends in the abundance and distribution of species whose existence depends on wetland habitats,
- Provide quantitative estimates of habitat quality for prioritizing critical habitats and assessing success of plan actions.

Programmatic Monitoring

Administrative monitoring for habitat gains and losses will provide data necessary to directly or indirectly assess attainment of Habitat Objectives 1, 2, 4, 5, 6, and 8. Programmatic data information needs to address each of the objectives individually include:

- Acres of vegetated wetlands created or restored,
- Records of acres of wetlands transferred to public ownership,
- Data indicating level of impact of economic and tax incentive programs,
- Documentation of beneficial use of alternative materials.

Accounting for acres of vegetated wetlands will draw information from numerous sources including the environmental monitoring element for habitat. Various projects are being conducted in the bay area to create or restore vegetated wetlands. The Galveston Bay Program will monitor these efforts annually to compile records of wetland gains or losses. The COE permit records will be a source of information concerning wetland losses through the Section 404 permitting process and records on wetland mitigation efforts. Other key sources of information will be the NMFS, UFWS, TPWD, EPA, GLO and The Galveston Bay Foundation.

Acquisition of wetlands for public ownership and management may be accomplished through state, federal and private programs. All of these means will be pursued and records of conversion to public ownership will be maintained.

The Plan recommends implementation of a "Wetlands Exemption" among other tax and development disincentive programs. Once implemented, records of requests and approvals for such exemptions and general data on wetland conversions will provide information to assess this action.

Programs supporting the beneficial use of dredge materials for habitat creation or restoration will be monitored. Programs will include the use of thin layer deposition of dredge material on subsiding marshes and use of dredge material to create bird nesting islands. Records of such activities will be maintained and used to evaluate the effectiveness of Objectives 1, 3, and 8.

An integrated bay-wide erosion management program will be developed as part of Objective 9. Information on subsidence, a contributing factor in wetland habitat losses through inundation and erosion, will be collected and made available by the Harris-Galveston Coastal Subsidence District. A bay-wide system for ranking erosional areas will be developed by the GLO and SCS. Other activities that relate to this Objective are items from Objectives 2 and 3 concerning beneficial uses of dredge materials.

Environmental Monitoring

Environmental monitoring of habitat distribution and condition in and around the Galveston Bay estuary will provide data necessary to directly or indirectly assess the cumulative effects of almost all habitat objectives. This discussion is divided into two sections: Areal Extent, Distribution, and Classification discusses methods to monitor changes in the amount and distribution of habitats; and habitat function and value describes a method to be used to evaluate the relative condition of key indicator habitats based on their suitability for serving various ecological functions and values assigned to them.

Areal Extent, Distribution, and Classification

The methods used to classify Galveston Bay habitats and monitor their areal extent and distribution must be capable of differentiating various wetland types and quantifying their extent with an acceptable level of accuracy. To ensure comparability, the classification system used should be shown to be comparable with previously conducted evaluations. Because changes in habitats are pervasive and can be rapid the program must be capable of frequent and cost-effective classifications

Two existing monitoring programs were identified as potentially meeting the requirements of this program: the USFWS National Wetlands Inventory (NWI) and the NOAA Coast Watch Change Analysis Program (C-CAP). The NWI database on the extent and characterization of wetlands in the U.S. is based primarily on aerial photography. This method of assessment is time consuming, labor intensive and as a result expensive. C-CAP is a nationally standardized database on land cover and habitat change in the coastal regions of the U.S. with a goal of better understanding the linkages between coastal and submerged aquatic habitats and abundance and health of living resources. (Dobson, et al., 1993) C-CAP utilizes standardized computerized approaches to classify and monitor coastal habitats from satellite thematic mapper (TM) multi-spectral imagery.

The Monitoring Work Group selected the C-CAP protocol as the one which best met the requirements of assessing plan objectives. The primary advantages of landcover mapping with satellite imagery using C-CAP protocol are: 1) it has standardized mapping classifications consistent with other major wetland classification systems, 2) extensive coverage can be obtained within a single satellite scene, 3) because it utilizes computerized classification schemes, classification and mapping can be accomplished over a relatively short period of time, in a cost effective way and 4) the classified landcover information is in a format readily integrated into GIS technology.

Major products available for Texas coastal areas are: 1) wetland landcover inventories for all Texas coastal wetlands, 2) change analyses information produced for each bay system at 3-5 year intervals, 3) input and integration of the landcover data and landcover change data with other natural resources data bases (e. g. coastal fisheries data, 404 permit data, hydrologic modeling, oil spill trajectory model, etc.) for the development of a comprehensive coastal GIS data base. (Personal correspondence, James Hinson, TPWD).

The TPWD program utilizes a supervised maximum-likelihood classifier to achieve land cover classifications. The land cover classification scheme used for Texas coastal zone habitat mapping by the TPWD includes land-cover types listed in Table 4-2 (Pulich, et al., 1992). A complete listing of landcover types and additional land-cover information is given in Appendix B (Klemas, et al., 1993). Numerous sources of ancillary data are also used to improve classification accuracy. For example, submerged aquatic vegetation cannot be classified from satellite imagery; aerial photography and other ancillary data is used to provide SAV classifications.

Hinson et al. (1994) conducted an evaluation of the accuracy of wetland and landcover classification using TM imagery. Ground-truthing techniques demonstrated that accuracy exceeding 85%, compared to the NWI classification, could be achieved for 10 major wetland landcover classes. It is recommended that ground-truthing be conducted as a Quality Assurance/ Quality Control measure to assure that this level of accuracy is maintained.

Habitat Function and Value

Functions, particularly when referring to wetland habitats, are the ecological benefits that a habitat provides. Wetland functions include fish and wildlife habitat, nursery habitat, and food web support among others. Habitat values are a measure of the human benefits provided by a habitat. Wetland values include flood

TABLE 4-2. LAND COVER CLASSIFICATION SCHEME USED FOR COASTAL ZONE HABITAT MAPPING AND ANALYSIS.*

LEVEL 0	LEVEL 1	LEVEL 2	ATTRIBUTES
WETLANDS	Marine		
	Estuarine	Aquatic Bed	Submerged Veg.
		Low Salt Marsh	S. alterniflora zone
		Brackish Marsh	Herbaceous
		Brackish Shrub	Woody zone
		Mud Flats	Tidal zone
		Open Water	0.5-30.0 ppt
	Palustrine	Fresh Marsh	Emergent Veg.
		Open Water	< 0.5 ppt
	Riverine	Emergent Veg.	Riparian
UPLANDS	Grasslands	Coastal Prairie	Native Pasture
	Woody Veg.	Shrub/scrub	Tallow, Willow, Cane, Brush land
		Forested	Oak, Hardwoods
	Agricultural	Cultivated	Croplands
	Developed	Industrial	Buildings
		Residential	Buildings
	Exposed Land	Beach, Sandflats	Natural Ground
		Roads, Levees	Disturbed

* From Pulich et al., 1992.

control, groundwater recharge, and recreational opportunities. A degraded habitat is defined as one which no longer performs one or more of its function or value roles. Using this definition we can then attempt to make measures of habitat quality in terms of ability to perform these roles. Quantifying wetland habitat quality allows managers to monitor trends in habitat quality that cannot be measured by extent and distribution. There is no widely accepted method for monitoring habitat quality in the Galveston Bay system.

A number of standardized techniques have been used for assessing habitat quality including Wetland Evaluation Technique (WET), Habitat Evaluation Procedure (HEP), and the Wetland Value Assessment Methodology (WVA). Each of these methods has strengths and weaknesses. The method proposed by the Monitoring Work Group is the Wetland Value Assessment Methodology. This method was selected because it was designed to be rapid, easily applied, and utilizes existing or readily obtainable data for its assessments.

WVA (USFWS, 1991a) is a quantitative habitat-based assessment methodology which can be used to quantify changes in wetland quality and quantity. Developed as a ranking method by the USFWS Lafayette, LA office, WVA is a modification of the HEP also developed by the USFWS. WVA differs from the HEP in that HEP uses a species-oriented approach, whereas the WVA utilizes a community approach. WVA works under the premise that optimal conditions for a wetland can be characterized and that an index of wetland quality can be developed by evaluation of a wetland against that optimal condition. This is accomplished by development of suitability index graphs for each of the defined variables. A suitability index is a graphical representation of how the overall quality or suitability of a given wetland type is predicted to change as values of the given variable change (USFWS, 1991a).

This method uses seven variables for assessment of three marsh types and cypress-tupelo swamp. These marsh types are Fresh/intermediate, brackish marsh, and saline marsh. Suitability index graphs are available for the following variables:

- Percent of wetland covered by persistent emergent vegetation (≥ 10% canopy cover,
- Percent of open water area dominated (> 50% canopy cover) by aquatic vegetation,
- Marsh edge and interspersion,
- Water duration in relation to marsh surface,
- Open water depth in relation to marsh surface,
- Mean high salinity during the growing season,
- Aquatic organism access.

It must be cautioned that WVA was developed specifically for use in Louisiana coastal wetlands including fresh marsh and intermediate marsh, brackish marsh, and saline marsh. Although Galveston Bay wetland habitats may be similar to those found in Louisiana, field testing and possible revisions will be required before the WVA methodology can be widely applied to Galveston Bay wetlands. The USFWS will take the lead in evaluation and development of a suitable habitat quality assessment tool. Additional decisions on monitoring frequency and site selection procedures will also need to be developed.

Colonial Waterbird Habitat

Assessment of colonial water bird habitat is a controversial issue and there is a wide range of opinions on the value of conducting any such assessments. The Texas Colonial Waterbird Census (TCWC) monitors colonial waterbird nesting sites in the Galveston Bay estuary. This program does not include evaluation of habitat extent or condition so information from the project as currently conducted cannot directly address the Habitat issue. However, the ultimate measure of habitat protection programs is measured in abundance and distribution of colonial bird species. The TCWC program provides nesting site utilization data which can be used to address Actions HP-7 and 8.

The Monitoring Work Group does not recommend conducting any type of habitat assessments requiring presence on the islands during nesting. The Work Group believes that disturbances from any such effort would cause greater harm to these colonies than any value that would be derived from such evaluations. Some evaluations of habitat that can be made from remote locations during bird counts may provide information on general habitat quality have been recommended. A list of candidate indicators and measures is given in Table 4-1. The Monitoring Work Group recomends that the Galveston Bay Program work with the USFWS to consider the value of conducting habitat evaluations for colonial bird nesting sites and to develop a methodology for assessments if deemed feasible and valuable.

CHAPTER 5

Species Population Protection

Priority Problems

The overall health of the Galveston Bay estuary, as measured by its diversity of species and the populations of its major recreational and commercial species, is generally considered to be good. However, populations of selected species within the estuary have experienced declines, with the primary suspected causes being loss of habitat, fishing, impingement/entrainment, and other types of human intervention. Because species within the estuarine environment are dependent on one another for maintenance of the food chain, the preservation of species populations is critical to the ecological health of the Galveston Bay system. Habitat preservation is the most essential requirement for effective protection of species populations, as the fate of species is closely linked to that of habitat. As is the case with habitat management, species population management is best carried out from a broad ecosystem perspective to ensure that an optimal variety and distribution of habitats are protected, as needed by the numerous species which are present within the estuary.

Management Goals and Objectives

Species Population Protection Task Force members initiated the development of objectives for the species population component of the Galveston Bay Plan. During Round 4 Task Force meetings, Task Force members established the following high-priority management goals:

- Reverse the declining population trend for affected species of marine organisms, and maintain the populations of other economic and ecologically important species.

- Eradicate or reduce the population of exotic/opportunistic species which threaten desirable native species, habitats, and ecological relationships.

These initial management goals were further defined and are now the six species population protection (SP) objectives and ten SP actions set forth in the Galveston Bay Plan :

Objective SP-1:	At a minimum, maintain fish and crustaceans at population levels within 50% of the 1975-1985 mean levels
Action SP-1.	Implement a bay-wide effort to strengthen species management
Objective SP-2:	At a minimum, maintain oyster population levels within 50% of the 1983-1993 mean levels
Action SP-2.	Return oyster shell to designated locations within the bay
Action SP-3.	Promote the development of oyster reefs using alternate materials.
Action SP-4.	Set aside a portion of reef habitat as scientific research areas or preserves.
Objective SP-3:	Reduce bycatch within the estuary by 50% by the year 2007, accounting for seasonal patterns
Action SP-5.	Encourage continued development of gear to reduce commercial bycatch
Action SP-6.	Conduct educational programs concerning catch and release.
Objective SP-4:	Reduce current levels of fish mortality caused by impingement/entrainment by 50% by 2007
Action SP-7.	Investigate potential measures to reduce impingement and entrainment
Objective SP-5:	Increase the populations of endangered and threatened species
Action SP-8.	Develop management plans for endangered and threatened species
Objective SP-6:	If feasible, by the year 2005, reduce abundance's by 10% for selected exotic species, including nutria and grass carp
Action SP-9.	Improve enforcement of prohibitions against the introduction of exotic species
Action SP-10.	Identify and implement techniques for the control of problem exotic species

Data Information Needs

The goal of Plan Objectives 1, 2, 3, 4 and 5 is to reverse the decline in population abundance for affected Bay organisms and maintain populations of economic and ecologically important species. Information needed to assess this management goal includes:

- Identification of commercial, recreational and ecologically important species of concern,
- Identification of indicator measures for identified species of concern,
- Status of and trends in abundance and distribution of identified species of concern.

The status of the abundance and distributions of identified species of concern provides a direct measurement for assessing whether Plan Objectives 1 through 4 are having their desired effect. Information on trends provides a means for evaluating whether progress is being made toward meeting these objectives. Measurements of the extent and quality of required or preferred habitats also provide a reasonable means to indirectly assess the potential for maintenance or recovery of identified species of concern.

Plan Objective 5 calls for maintaining and enhancing abundance of threatened and endangered Bay species. Information needed to assess this management objective include:

- Identification of threatened and endangered Bay species,
- Identification of indicator parameters for identified threatened and endangered species,
- Status of and trends in abundance and distribution of identified threatened and endangered species.

The status of the abundance and distribution of identified threatened and endangered species provides a direct measurement for assessing whether these species are recovering in accordance with Plan Objective 5. Information on trends provides a means for evaluating whether progress is being made toward meeting this objective.

Threatened and endangered species have already been identified by the USFWS. Whenever possible, direct measurements of abundance for threatened and endangered species of concern is the recommended metric. If direct measurements are not feasible, the use of reliable indicator species is highly recommended. In addition, measurements of the extent and quality of required or preferred habitats provide a means to assess the potential for recovery of these special status species.

The goal of Plan Objective 6 is to maintain and reduce abundance of exotic, nuisance species. Information needed to assess this management objective include:

- Identification of exotic nuisance Bay species,
- Identification of indicator parameters for identified exotic nuisance species,

- Status of and trends in abundance and distribution of identified exotic nuisance species.

The status of the abundance and distribution of identified exotic nuisance species provides a direct measurement for assessing whether these species are being controlled in accordance with the plan objective. Information on trends provides a means for evaluating whether progress is being made toward meeting this objective. The two most important exotic nuisance species have already been identified by GBNEP: nutria and grass carp.

Task Force members agreed that an assessment of ecosystem condition required the evaluation of the status and trends in the abundance and distribution of several selected indicator species as well as a suite of physical and chemical parameters. Recommended physical and chemical parameters were considered in the development of the Water /Sediment Quality monitoring plans.

Monitoring activities must provide information to evaluate whether progress toward these management objectives is being made. The species population protection component of the regional monitoring program must provide data to assist in:

- Determining whether severe alterations in populations and communities are occurring,
- Identifying potential causes of alterations in populations and communities,
- Evaluating alternative actions to mitigate identified adverse impacts to important populations and communities.

The following monitoring objectives were used to develop the monitoring strategy:

Phytoplankton

- Determine the status of and trends in primary productivity,
- Determine the status of the abundance and distribution of dominant phytoplankton,

Benthic Invertebrates

- Determine the status of and trends in the abundance and distribution of dominant species.

Selected Fish and Shellfish

- Determine the status of and trends in relative abundance (i.e., catch per unit effort [CPUE]) and distribution of selected species,
- Determine the status of and trends in abundance of food (use estimates from phytoplankton data),

- Determine the status of and trends in the areal extent and quality of nursery and feeding habitats.

Selected Birds and Reptiles

- Determine the status of and trends in abundance and distribution of selected species,
- Determine the status of and trends in the areal extent and quality of required habitat.

Assessments of the abundance of species populations of concern will be based on the weight of evidence from measurements of species of concern or indicator species abundance and the extent, quality of required or preferred habitats. From identified Plan objectives and information needs, it is clear that the species population component of the regional monitoring program must provide both local and bay-wide status and trend data.

Programmatic Monitoring

Environmental monitoring will be the ultimate source of answers to the effect of the plan on living resources in the bay. However, during plan implementation and the intermediate years before meaningful environmental information is available, programmatic monitoring will provide the only means for assessing plan progress. Examples of programmatic actions which may be tracked are:

- New species management plans adopted by the Galveston Bay Interagency Advisory Committee,
- Progress in obtaining funding for the oyster shell return program,
- Creation of oyster reefs using alternative materials,
- Quantity of oyster reef habitat as research area or preserve,
- Identification of gear and devices for reducing by-catch and the level of implementation within the commercial fishery,
- Conduct surveys to assess the effect of catch and release educational programs,
- Implementation of technology to reduce impingement and entrainment,
- Number of management plan developed and adopted for endangered or threatened species, and
- Identified and implemented techniques for the control of exotic species.

Environmental Monitoring

Because it is not feasible to measure all environmental parameters, a limited set of indicator parameters were identified as candidate monitoring parameters for the species population component of the regional monitoring program. These candidate indicators and species of concern are shown in Table 5-1. These suggested indicator species were selected because they represent important commercial, recreational, and ecological groups. Phytoplankton abundance and community structure will

TABLE 5-1. CANDIDATE INDICATORS AND MEASUREMENTS FOR SPECIES PROTECTION

Candidate Indicator	Candidate Measurement
Ecologically Important Species / Communities	
• Plankton community	Chlorophyll-a ; pheophytin-a(See Water Quality)
• Benthos	Community structure (See Sediment Quality)
• Shellfish	
- white shrimp	Abundance and distribution
- brown shrimp	Abundance and distribution
- blue crabs	Abundance and distribution
• Finfish	
- Atlantic croaker	Abundance and distribution
- gulf menhaden	Abundance and distribution
- anchovy	Abundance and distribution
• Birds	
Colonial waterbirds	Abundance and distribution
Shorebirds	Abundance and distribution
Wintering waterfowl	Abundance and distribution
• Alligator	Abundance and distribution; # nests
Commercially and Recreationally Important Species	
• Shellfish	
- eastern oyster	Areal extent of reefs; distribution; density; size
- white shrimp	Abundance and distribution; size; weight
- brown shrimp	Abundance and distribution; size; weight
- blue crabs	Abundance and distribution; size; weight
• Finfish	
- Atlantic croaker	Abundance and distribution; size; weight
- black drum	Abundance and distribution; size; weight
- red drum	Abundance and distribution; size; weight
- gulf menhaden	Abundance and distribution; size; weight
- sand seatrout	Abundance and distribution; size; weight
- spotted seatrout	Abundance and distribution; size; weight
- sheepshead	Abundance and distribution; size; weight
- southern flounder	Abundance and distribution; size; weight
Commercial By-catch	*CPUE # and biomass; by-catch / shrimp biomass ratios*
Impingement / Entrainment	*Abundance;survival*
Introduced Exotic Species	
• grass carp	Abundance and distribution
• nutria	Abundance and distribution
Threatened and Endangered Species	
• brown pelican	Abundance and distribution
• piping plover	Abundance and distribution
• sea turtles	Sightings
• snowy plover	Abundance and distribution
• diamondback terrapin	Abundance and distribution

provide information characterizing primary productivity and the quantity and quality of the base of the aquatic food web. Benthic macro-invertebrate abundance and community structure will provide information to characterize an important guild of primary consumers that serve as key prey items for many shrimp, crab and fish predators in the Bay. Benthic macro-invertebrates are closely associated with Bay sediments and infaunal data can be used to infer the toxicity of Bay sediments. Selected finfish and pelagic macroinvertebrates are not only commercially important but represent intermediate consumers in the system. Bird, reptile, and mammal data will provide managers with information on the top consumers in the system.

Phytoplankton

Phytoplankton plays an important role as a primary producer in estuarine ecosystems. Phytoplankton communities are susceptible to a number of anthropogenic influences such as excess or deficient nutrient input and changes in salinity. Because of the relatively short life span and high growth potential of this indicator, changes in environmental quality can lead to rapid changes in abundance. For these reasons, phytoplankton provide an excellent indicator of ambient conditions. Phytoplankton monitoring does not directly assess any objective but provides valuable supportive information for Objectives 1 through 4.

Phytoplankton biomass will be estimated through the measurement of chlorophyll-a and pheophytin-a concentrations using spectrophotometric analysis. Chlorophyll-a samples will be collected as a Tier One water quality parameter at all open bay stations 4 times a year. Sampling and analytical protocols are those listed in the TNRCC *Draft Water Quality Procedures Manual* (TNRCC, 1993) and the most recent edition of *Standard Methods for Examination of Water and Wastewater* (APHA, 1992). Determinations of cost and data value from HPLC analytical techniques will be evaluated. Recent publications (Buskey and Schmidt, 1992 and Wright, et al., 1991) suggest that HPLC measures of phytoplankton pigments can be used to estimate the relative composition of major taxonomic groups in the samples. The ability to conduct community structure evaluations of phytoplankton is desirable. However, there are not current programs to perform these evaluations. This will be recommended as a parameter for future consideration.

Phytoplankton communities in Galveston Bay show considerable seasonal and long-term variability and are characterized by a series of small blooms that occur throughout the year (Buskey and Schmidt, 1992). This variability may be influenced by any number of factors including light availability, nutrients , and water temperature. Because of this variability it is recognized that quarterly sampling for chlorophyll pigments, as recommended in the water quality sampling section of this plan, is not in itself adequate to characterize phytoplankton communities in the system. The use of continuously recording *in situ* fluorometers at fixed sites will be pursued as a supplement to the recommended monitoring.

The TWDB has plans to upgrade their existing network of data sondes, with new sondes equipped with *in situ* fluorometers. This will be accomplished through attrition, replacing older instrumentation which is taken out of service with upgraded sondes. This will enable continuous, *in situ* measurement of chlorophyll concentration, integrated electronic storage of the data, and simultaneous collection of associated water column data (such as, transmissivity, dissolved oxygen, depth, temperature, and conductivity). Because both fluorometric and spectrophotometric methods measure chlorophyll-a concentrations, the resulting data are comparable. However, samples analyzed using different techniques should not be combined for statistical analyses.

Benthics (see Sediment Quality)

Fish and Shellfish Monitoring

A number of independent monitoring efforts are conducted in Galveston Bay for selected species of marine organisms. The three major programs are the TPWD Coastal Fisheries Program, the NMFS Baseline Production Program, and the TNRCC Nekton Sampling Program. The program objectives and sampling plans for each of these programs were evaluated against plan objectives. Although each of these programs provides valuable information for the assessment of bay living resources, the TPWD Resource Monitoring Program was selected as being best suited for evaluating the stated objective.

On a monthly basis 20 trawl, 30 oyster dredge, and 20 bag seine samples are collected in Galveston Bay. Additional trawl and seine samples are collected in the Gulf Intracoastal Waterway, beach, and offshore sites. Sampling sites are selected randomly from a grid system to ensure an equal chance of sampling each section of shoreline and open bay water. The appropriate sampling technique is selected based on the time of the year and location of the sampling station. Sampling techniques are described in the Marine Resource Monitoring Operations Manual (TPWD, 1993). All organisms greater than 5 mm in length are identified to species level and counted. Samples are analyzed for species identification, number of specimens, size, weight, sex, and maturity are recorded for selected individuals.

A stated objective of the TPWD Coastal Fisheries Resource monitoring Program is to assess annually the status of finfish, shrimp, crab, and oyster populations and associated environmental variables in the coastal waters. Available monitoring data support the viability of management objectives 1 and 2. Existing data indicate that, for selected commercially and recreationally important species, current monitoring efforts allow managers to detect changes from present overall mean abundance— plus or minus 50 percent — with acceptable statistical power (power = 0.8). In addition, current efforts allow detection of 10% or greater trends in mean population abundance's over a ten-year interval (L. McEachron and A. Green, TPWD, personal communication).

Oysters are an economically and ecologically important species in Galveston Bay. Because of their sessile nature, changes in the abundance and distribution of oysters provide an excellent means for assessing environmental conditions in an area. TPWD is the only agency conducting routine monitoring of oyster condition in Galveston Bay. As part of their Resource Monitoring Program samples are collected from known oyster reefs. Monthly sampling is based on counting live organisms collected from a series of 30-second oyster dredge trawls. Counts of oyster spat, encrusting organisms, and the percentage of live and dead oysters are recorded. Standing crop estimates are made from the number of organisms collected on a per-effort basis.

GBNEP also sponsored a survey of the location, extent and areal extent of oyster reef habit. This was accomplished using acoustic profiling techniques described by Powell et al. 1994. It is recommended that the Galveston Bay Program sponsor regular but infrequent surveys, possibly every 10-15 years, be conducted for areal extent using this technique.

Bird Populations

The Galveston Bay estuary is home to a number of important bird species throughout the year. The area also produces important nesting and wintering habitat for a large number of migratory species. Birds fill a variety of roles in the trophic structure of an ecosystem and may, depending on the species, be primary consumers, secondary consumers, or top carnivores. Because of their diversity and the wide open range of ecological roles filled by birds, monitoring of this group is essential to measuring the health of the estuary. Three guilds of birds have been selected for monitoring for abundance and distribution. These guilds are; colonial nesting waterbirds, shorebirds, and migratory waterfowl.

Several existing bird surveys are conducted in the Galveston Bay system. The TPWD and U.S. Fish and Wildlife Service (USFWS) conducts an annual survey of colonial nesting waterbirds along the Texas coast. These surveys are conducted during a two-week period beginning the last week of May. Ground counts are made by two to four persons viewing the colony from boat or on foot. Standardized procedures have consistently been followed during the censuses and established data forms have been used since 1986. This survey provides quantitative information on total numbers of individuals, numbers of active colonies, and the mean number of individuals per colony. This data set is well suited to multivariate data analysis. (Slack, et al., 1992)

The USFWS, Clear Lake office, has conducted irregular monthly surveys of shorebird feeding habitats continuously since 1980. A strength of the program is the use of multiple observations during the year, which allows for increased reliability of annual population estimates. (Slack et al., 1992). Past surveys have only been conducted in one area, the Bolivar Flats, this limits the information on spatial distribution of shorebirds in the estuary. This program has been discontinued, but it is the recommendation of the Monitoring Work Group that it be reinstated and expanded. Expanding the surveys to other locations will increase the availability of data on spatial distribution. Three proposed areas are continuation at Bolivar Flats, and expansion of the program to San Luis Pass and the Big Reef area. It is also recommended that the surveys be conducted at regular intervals during the year to reduce temporal sampling biases.

The TPWD, in conjunction with the USFWS, has conducted an annual Mid-winter Waterfowl survey since 1973. This survey consists of one systematic scheme of sampling along transects and another less systematic sampling scheme of counting birds in general locations. These data provide information on abundance of waterfowl by species and by transect, or by general location within the surrounding waters of the Galveston Bay system.

Data from each of these monitoring programs was evaluated as part of a program to characterize the status and trends of selected endemic resources of the bay ecosystem. The objectives were to evaluate the validity of available data sets for use in the characterization of living resources and to conduct analyses of selected avian populations and assemblages. (Slack, et al., 1992) A discussion of the data set validity and results for each of these data collection programs is given in this document. A number of recommendations are made which would improve the statistical power of the programs' data collection efforts. All of these recommendations will be considered for implementation of further data collection efforts.

Reptiles

The American alligator (*Alligator mississippiensis*) is a large, wetland dependent, commercially important, vertebrate predator. As such, alligator populations are greatly influenced by a variety of human activities including loss of wetlands, pollution, and hunting. It is for this reason that the alligator was selected as an indicator species in the GBRMP.

The TPWD is responsible for regulating annual alligator harvest in Texas (Slack, et al., 1992). This requires information on the present status of alligator populations and their recruitment rates. To obtain this information, the TPWD conducts night counts of alligators and helicopter surveys of alligator nests along the Texas coast. Surveys were conducted annually from 1980 to 1984 and triennially since 1985. Established transects are located in the marshes adjacent to East Bay and Trinity Bay. Night counts are made along transects of variable lengths using observers to count individuals. Nest count transects are made from a height of 90 meters along transects spaced at 1.5 km intervals. Surveys are conducted in May when the height of marsh vegetation is low.

By-catch

There are no ongoing monitoring programs to address Objective 3, reducing by-catch. Without new gear and/or devices being implemented, the value of frequently scheduled by-catch studies is questionable. The Monitoring Work Group recommends that requirements and trends in implementation of new gear and devices be monitored to trigger actual by-catch studies in the future or that by-catch studies be conducted on an infrequent basis, i.e. every 2 years. The TPWD has adopted a by-catch protocol which is based on the GBNEP by-catch study conducted by the NMFS. This protocol will be evaluated for comparability to the NMFS protocol. If found to be comparable, future by-catch monitoring programs could be conducted by the TPWD or NMFS.

Impingement / Entrainment

Objective 4 calls for reductions in levels of fish mortality caused by Impingement/Entrainment by 50% by 2007. Two separate monitoring elements will be used to assess this goal. The TNRCC routinely collects impingement data from intakes at one HL&P power station and one major chemical industry (G. Guillen, TNRCC, personal correspondence). These data have utility as a baseline measure of impingement at those and other sites with similar impingement reduction technology. When improved technology is implemented, continuation of data collection should provide useful information in assessing impingement reductions. Similar monitoring may be implemented at other plants to provide additional information.

HL&P is conducting studies to measure the effectiveness of newly installed pumping systems and other impingement/entrainment reduction methods in reducing entrained organism mortality. Development and implementation of proven technology to reduce impingement/entrainment will be tracked as an assessment of Objective 4.

Endangered, Threatened and Candidate Species

There are no existing monitoring efforts specifically for endangered species. Threatened and endangered monitoring for bird species will generally be covered within other monitoring programs. For example, Slack, et al, 1992, reports that brown pelican and piping plover sightings were commonly reported in the TCWS and Shorebird Surveys of Bolivar Flats data sets. Brown pelicans were reported infrequently in the TCWS and Shorebird Survey of Bolivar Flats, and piping plovers were frequently reported in the Shorebird Surveys at Bolivar Flats.

Current monitoring for sea turtles is by public reporting of sightings in the bay. A possible extension of this program would involve the establishment of public access points in areas where sea turtles have been observed (e.g., based on Manzella and Williams, 1992, as referenced in Tetra Tech, 1994b). These displays would encourage public participation by requesting visitors to record the amount of time they spent in an area, any turtles observed, and other pertinent information. In addition to public sightings there are some more intensive studies utilizing telemetry to track movements of individual turtles. Information from the tagging program can be used to select target areas for establishing public information displays.

The Texas diamondback terrapin and the southeastern snowy plover are currently listed as Category 2 candidate species. Candidate 2 species are taxa for which available information would indicate a listing of endangered or threatened may be appropriate, but for which conclusive data to support such a listing is not currently available (USFWS, 1991b). Further biological research and field study are needed to ascertain the true status of these species. Information on the southeastern snowy plover may be obtained from the shorebird populations monitoring program, but there is no current methodology for monitoring the Texas diamondback terrapin.

Data indicate that drowning in crab traps is a major threat. One possible monitoring technique would be to establish a public information/reporting system for reporting their occurrence in crab traps. This is a monitoring need that will be addressed.

Introduced Exotic Species

Some exotic/opportunistic species, such as nutria and grass carp, threaten desirable native species, habitats, and ecological relationships. Significant populations of nutria, a large beaver-like rodent which strips vegetation within freshwater and brackish water marshland, and grass carp, which strip aquatic vegetation, have been reported in the Trinity River and San Jacinto River portions of the estuary. Monitoring for introduced exotic species will be required to assess the effectiveness of techniques for attaining 10% reductions, by the year 2005, in populations of problem exotic species. Current monitoring for these species is not adequate to proved information needed to assess this plan objective.

In 1992 and 1993 the TPWD and Texas A&M University (TAMU) conducted a survey for grass carp in the lower Trinity River. The purpose of this survey was to address concerns over the presence of growing grass carp populations and possible predation on smooth cord grass in the estuary (Webb, et al., 1994). Results of this survey indicate the probable presence of a reproducing population of grass carp in the study area. During the 1992 sampling period, viable eggs but no larvae were found; in the 1993 survey viable eggs and recently-hatched larvae were found in substantial numbers. Additionally, a significant commercial fishery for grass carp exists on the river and fish kill data have documented juvenile grass carp in the Bay system.

Adult grass carp from commercial fishing efforts were examined for a number of characteristics including ploidy. In a sample size of 153 adult grass carp examined for ploidy, 85% were found to be diploid and 15% were triploid. During the 1992-93 surveys no juvenile or adult grass carp were collected using conventional fish collection techniques including gill nets and electrofishing. The absence of grass carp from this sampling effort would indicate the difficulty in effectively monitoring grass carp using traditional collection techniques. Suggestions for future monitoring include tracking studies, annual monitoring of adults, and periodic sampling for juveniles.

An informal group including representatives from the SCS, TPWD-Coastal Fisheries, TPWD-Inland Fisheries, TAMU, the Galveston Bay Foundation and GBNEP has met to discuss possible monitoring and control strategies. At this meeting it was recommended that the first step, in assessing the distribution of grass carp in the Galveston Bay system, be development of a map documenting sites of grass carp identifications. The TPWD-Coastal Fisheries office has agreed to compile this data from a review of fish kill reports and fisheries data base reports. This should be available by January 1995.

A similar group will be convened to address the issue of nutria populations. There is no current monitoring program to assess nutria populations. Monitoring the size of nutria populations over any large area is difficult due to the habitat these animals are found in and their behavior (Greg Linscombe, Louisiana Department of Wildlife and Fisheries, personal communication). Nutria have a small home range and their densities fluctuate greatly depending on habitat type (Kinler et al., 1987). Mark and recapture methods are therefore only useful for small areas of continuous habitat. It is recommended that population monitoring focus on tracking changes in the relative abundance of nutria by developing an index based on some measure of their activity in selected areas.

Except during periods of extreme cold, nutria are most active at night (Kinler et al., 1987). Changes in their relative abundance could be monitored using transect or point count methods by spotlighting at night. However, in areas of dense vegetation, visual counts would be extremely difficult and could provide inconclusive or misleading data. Alternatively, an index could be established based on some other indicator of their activity such as scat counts, active trail counts, or evidence of feeding activity (Kinler et al., 1987). It is recommended that the TPWD in conjunction with the Galveston Bay Program office, undertake a special study to identify effective techniques best suited to the Galveston Bay estuary.

Chapter 6

Public Health Protection

Priority Problem

The Galveston Bay Estuary is the state's largest source of seafood, and is one of the major oyster producing areas in the country. Commercial and recreational fishing represents a nearly one-billion dollar industry, and molluscan shellfish (e.g., oysters) and other seafood (e.g., crabs, shrimp, and finfish) harvested from Galveston Bay are consumed by millions of individuals. Maintenance of adequate public health standards within estuarine seafood is important for the protection of the general public, and is also critical for the long-term stability of the fishing industry.

The Texas Department of Health has controlled the harvest of shellfish from Galveston Bay for approximately 40 years, and the quality of produced molluscan shellfish has been maintained at a level which has posed a minimal risk of illness. However, limited funding is available for this shellfish program, and accordingly, shellfish closures are believed to be larger than would be necessary with a greater frequency of field sampling. To address this problem, an expansion of the shellfish sampling program, including more frequent sampling, is recommended.

Galveston Bay receives the largest total amount of industrial and municipal effluent of all Texas estuaries, and also receives significant amounts of contaminants from non-point sources via stormwater runoff. Loading estimates for a large number of metals and organic chemicals are incomplete, and insufficient data are available regarding the distribution of potentially toxic compounds within estuarine waters and sediment. Fish and shellfish from Galveston By are not routinely sampled for toxic contaminants, nor are consumer risks routinely assessed by any government entity and communicated to the public. To address this situation, the Public Health Protection Task Force of GBNEP recommends additional research to establish risk-based standards for toxic contaminants within seafood. Based on established standards, the implementation of a seafood sampling, analysis, and risk communication program is recommended to safeguard the quality of seafood produced form the Galveston Bay Estuary.

Management Goals and Objectives

Public Health Protection Task Force members considered objectives for the Public Health portion of the Galveston Bay Plan. During Round 4 Task Force meetings, Task Force members established the following high-priority management goals:

- Reduce potential health risk resulting from consumption of seafood contaminated with toxic substances,
- Reduce oyster reef harvest closures,
- Minimize risk of water-borne illness resulting from contact recreation.

These initial management objectives were further modified and are now the three public health protection objectives and three actions set forth in the Galveston Bay Plan :

Objective 1	By the year 2000, reduce the risk of consumption of Galveston Bay seafood containing tissue concentrations of toxic substances above risk level standards established by the TDH.
Action PH-1	Develop a seafood consumption safety program
Objective 2	Increase oyster reef areas open to harvest by 25% on a spatial and temporal basis by 31 August 1995, as compared to a 1988 baseline
Action PH-2.	Enhance the TDH shellfish sanitation program
Objective 3	By the year 2000, establish a contact recreation advisory program in all areas of the estuary commonly used for contact recreation
Action PH-3.	Develop a contact recreation advisory program

Data Information Needs

Because it is not feasible to measure all environmental parameters, a limited set of indicator parameters were identified as candidate monitoring parameters for the public health component of the regional monitoring program and are briefly discussed in this chapter.

Plan Objective 1 is to reduce potential health risks resulting from the consumption of seafood contaminated with toxic substances. Information needed to assess this management objective include:

- Identification of contaminants of concern (COCs),
- Identification of species of concern for tissue sampling,
- Status and trends in the concentration and distribution of COCs in commercial and recreational fish and shellfish,
- Status and trends in fish and shellfish consumption rates for specific human populations around Galveston Bay , and
- Specific criteria to assess fish and shellfish toxicity.

Fecal coliform monitoring for the National Shellfish Sanitation Program (NSSP) determines harvest closures for Galveston Bay oyster reefs. Objective 2, enhancement of the NSSP monitoring program, was developed under suggestions by TDH that with more frequent monitoring reef closures could be reduced. Because of the special regulatory requirements for this monitoring program the GBRMP will not develop a monitoring strategy to address this objective. The GBRMP fecal monitoring program can provide useful information for general assessment of water quality but it cannot be used by the NSSP to evaluate shell fish monitoring areas. The Monitoring Steering Committee will work with the TDH to assist in the accomplishment of this goal.

Plan Objective 3 attempts to minimize the risks of water-borne illness resulting from contact recreation. Information needed to assess this management objective include:

- Infectious disease reports for Galveston Bay,
- Relationship between water-borne illness and indicator organism concentration
- Status and trends in the magnitude and distribution of indicator organisms,

The status and trends in abundance of indicator organisms are needed to characterize pathogen levels in Bay waters and to assess whether these levels pose a risk to human populations. Trend data are needed to assess whether progress is being made toward minimizing health risks due to water-borne pathogens.

Alternative candidate indicator parameters for pathogens have been suggested. Task Force members agreed that until other indicator organisms had been tested and approved, fecal coliform bacteria would remain the indicator organism for human pathogens. Members highly recommend that the use of other indicators of human pathogens (e.g., *Enterococcus, E. coli*) be investigated and considered for inclusion into the regional monitoring program at a later date.

The following monitoring objectives were used to design the regional monitoring program for Galveston Bay:

- To make bay-wide estimates; in terms of areal extent (±10%), and temporal trend, in terms of areal extent and magnitude, of exceedences in State human health numerical criteria for toxics.

- To make bay-wide estimates; in terms of areal extent (±10%), and temporal trend, in terms of areal extent and magnitude, those waters in violation of state criteria for fecal coliform bacteria.

Assessments of risks to public health will be based on the weight of evidence from several indicator parameters. From identified Plan objectives and information needs, it is clear that the public health component of the regional monitoring program must provide local and bay-wide status and trend data .

Programmatic Monitoring

Lines of responsibility for all Public Health objectives are clearly drawn. The TDH as the state agency with responsibility for all public health related issues is responsible for implementation of the Public Health Action Plan. *The Plan* specifically identifies the TDH as having responsibility for development and implementation of programs to reach the stated goals of the plan. *The Plan* designates the TDH as the agency responsible for developing a risk assessment methodology including development of standards and a monitoring program for toxics in tissues.

The Galveston Bay Program will closely monitor progress within the TDH, of programs leading to the accomplishment of the plan goals. Intermediate and ultimate information to be tracked to assess plan success are:

- Development of applicable standards for tissue monitoring program,
- Progress in obtaining funding for each of the programs,
- Increases in TDH sampling events for the NSSP,
- Increases in oyster reef areas open for harvest,
- Progress in development of alternative indicators for human pathogens,
- Tracking TDH reportable disease records for Galveston Bay

Environmental Monitoring

Monitoring activities must provide information to evaluate whether progress toward management objectives is being made. The public health protection component of the regional monitoring program must provide data to assist in:

- Development of a Seafood Consumption Safety Program in Galveston Bay,
- Evaluating alternative actions to reduce fecal coliform loads to the Bay,

No State agencies conduct routine ambient monitoring of toxic contaminant levels in fish tissues in Galveston Bay. (Tetra Tech, 1994b). Both the TNRCC and the TDH do collect and sample tissues on an episodic basis, in response to spills, toxic leaks, and other known accidental releases to the Bay. The focus of each agency is different. The TNRCC effort is in support of water quality monitoring while the primary concern for the TDH effort is human health risk.

Two federal monitoring programs have tissue monitoring sites within the bay. A fairly extensive tissue sampling effort has been conducted as part of the USEPA Environmental Monitoring and Assessment Program (EMAP) and Regional-EMAP programs. From 1991-1993 data is available for approximately 15 annual EMAP sites. EMAP has compiled contaminant levels of pesticides, heavy metals, and polychlorinated biphenyls (PCBs) in edible fish and shellfish tissues for three species groups: Atlantic croaker (*Micropogonias undulatus*), commercial shrimps (*Penaeus aztecus* and *Penaeus setiferus*) and marine catfish (*Arius felis, Bagre marinus,* and *Ictalurus furcatus*) (U.S. EPA, 1994). The R-EMAP data is from 32 sites in the bay but it is only a one time survey. The NOAA Status and Trends Mussel Watch Program samples six sites in Galveston Bay every two years. The data from this program is too sparse to provide detailed information on ambient conditions within Galveston Bay but it is valuable as an external data set for substantiating general trends.

As previously discussed, responsibility for development of the Seafood Consumption Safety Program falls to the TDH. TDH is currently developing a fish consumption risk assessment program (the Aquatic Life Survey Program), for application throughout Texas, for freshwater fish, saltwater fish, and shellfish (Table 6-1). Tissue concentrations of a large group of COCs, including 69 volatile and 70 semi-volatile organic compounds, 8 PCB aroclors, 25 pesticides, and 4 metals are recommended for monitoring (Table 6-2). This program will incorporate a regular ambient sampling effort to monitor trends in contaminant levels in seafood and the potential health risks associated with long-term fish consumption (Tetra Tech, 1994b).

Tissue sampling and analysis programs are costly and time consuming. For these reasons the Monitoring Work Group will work with the TDH to maximize the comparability of tissue collections in the Bay. TDH and TNRCC currently have similar protocols for collection and preparation of samples. The TDH laboratory performs, or supervises contract laboratories in, the analyses of all toxic contaminants in fish and shellfish tissue collected in Galveston Bay. USEPA recommended analytical methods are used for all tissue analyses.

The GBRMP will collect monitoring information which could be useful in development of the TDH monitoring program. Comparisons of water quality monitoring results to state human health water quality criteria will provide information with respect to status and distribution of toxics in the system. Texas state water quality criteria for protection of human health are risk- based criteria developed to prevent contamination of fish and other aquatic life and to ensure that they are safe for human consumption. These criteria were derived from information gathered from the USEPA Integrated Risk Information System (IRIS). Numerical human health criteria were derived from the general procedures and guidance found in the USEPA document, *Technical Support Document for Water Quality-based Toxics Control;* and *Guidance Manual for Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish* (USEPA, 1988). Monitoring elements to provide the necessary data needed for evaluations of objectives 2 and 3 are the GBRMP fecal coliform (FC) sampling data (see Chapter 10) and the NSSP fecal coliform data set as collected by the TDH. GBRMP samples are based on TNRCC methodology which utilizes the membrane filter technique. TDH uses the multiple-tube most probable number technique (Jensen and Su, 1992) . *Standard Methods* indicates that the two methods are equivalent, however the NSSP only recognizes the MPN procedure. As a result the FC data collected by the GBRMP cannot be utilized by the TDH to supplement the NSSP. However, both data sets will be utilized for monitoring status and trends for FC in the Bay.

Bay waters may be deemed unacceptable for recreation if fecal coliform levels exceed EPA and State of Texas water quality criteria, 200 colonies/ml for contact and non-contact recreation. Likewise, Bay waters may be deemed unacceptable for

TABLE 6-1. RECOMMENDED INDICATOR SPECIES FOR TDH AQUATIC LIFE SURVEY PROGRAM

Freshwater Fish	Saltwater Fish and Shellfish
Largemouth Bass	Black Drum*
White Bass	Red Drum*
Striped Bass	Speckled Trout
White Crappie	Sand Trout*
Black Crappie	Alligator Gar
Channel Catfish	Southern Flounder*
Blue Catfish	Sea Catfish
Flathead Catfish	Gafftopsail Catfish
Common Carp	White Shrimp
Smallmouth Buffalo	Brown Shrimp
River Carpsucker	Blue Crab*
Spotted Gar	Stone Crab
Longnose Gar	American Oyster*
Grass Carp	Sheepshead
	Atlantic Croaker*
	Tripletail

* These species are recommended by NEP Task Force to be used as indicators for toxic contamination levels in edible tissue.

shellfish harvesting if fecal coliform levels exceed, 14 colonies/ml, the TNRCC water quality criteria for shellfish growing waters.

The GBRMP FC monitoring element will also provide important information in support of the Contact Recreation Advisory Program to be developed by TDH. As stated in the plan this program will utilize either the TNRCC fecal coliform standard or an alternative indicator parameter to be developed by TDH. The Regional Monitoring Committee will work with the TDH in establishing stations and monitoring protocols for this program when it is developed.

TABLE 6-2. PROPOSED CONTAMINANTS OF CONCERN FOR TDH AQUATIC LIFE SURVEY PROGRAM

Volatile Organic Compounds:	**(ppb)**
Chloromethane	47
Bromomethane	47
Vinyl Chloride	47
Dichlorodifluoromethane	47
Trichlorofluoromethane	19
1,1-Dichloroethene	19
Methylene chloride	19
Carbon disulfide	19
1,2-Dichloroethene (trans)	19
1,2-Dichloroethene (cis)	19
1,1-Dichloroethane	19
Methyl-t-butyl ether	19
Bromochloromethane	19
2,2-Dichloropropane	19
Chloroform	19
Tetrahydrofuran	19
1,2-Dichloroethane	19
1,1,1-Trichloroethane	19
Benzene	19
Carbon tetrachloride	19
1,1-Dichloropropene	19
1,2-Dichloropropane	19
Dibromomethane	19
Trichloroethene	19
Dichlorobromomethane	19
Methyl methacrylate	19
Methyl isobutyl ketone	19
1,2-Dichloropropene (trans)	19
1,2-Dichloropropene (cis)	19
1,1,2-Trichloroethane	19
1,3-Dichloropropane	19
Toluene	19
Ethyl methacrylate	19
2-Hexanone	19
Dibromochloromethane	19
1,2-Dibromoethane	19
Tetrachloroethene	19
1,1,1,2-Tetrachloroethane	19
Chlorobenzene	19
Ethyl benzene	19
Bromoform	19
Styrene	19
1,1,2,2-Tetrachloroethane	19
Bromobenzene	19
1,2,3-Trichloropropane	19
Isopropylbenzene	19
n-Propylbenzene	19
2-Chlorotoluene	19
4-Chlorotoluene	19
1,3,5-Trimethylbenzene	19
T-Butylbenzene	19
1,2,4-Trimethylbenzene	19
Sec-Butylbenzene	19
1,3-Dichlorobenzene	19
1,4-Dichlorobenzene	19
P-Isopropyltoluene	19
1,2-Dichlorobenzene	19
N-Butylbenzene	19
1,2-Dibromo-3-chloropropane	19
1,2,4-Trichlorobenzene	19
Naphthalene	19
1,2,3-Trichlorobenzene	19
1,2,3-Trichlorobenzene	19
Hexachlorobutadiene	19
Total xylenes	56
Methyl ethyl ketone	94
Acetone	94
Acrylonitrile	94
2-Chloroethoxy-ethene	187

Semi-Volatile Organic Compounds:	**(ppm)**
Phenol	2
2-Chlorophenol	2
2-Nitrophenol	2
2,4-Dimethylphenol	2
2,4-Dichlorophenol	2
3-Methyl-4-chlorophenol	2
2,4,6-Trichlorophenol	2
2,4,5-Trchlorophenol	2
2,4-Dinitrophenol	4
4-Nitrophenol	4
4,6-Dinitro-2-cresol	4
Pentachlorophenol	4
n-Nitroso-n-dimethylamine	1
Pyridine	1
n-Nitrosodiethylamine	1
n-Nitrosodibutylamine	1
Aniline	1
Bis(2-chloroethyl) ether	1
1,3-Dichlorobenzene	1
Benzyl alcohol	1
1,4-dichlorobenzene	1
1,2-dichlorobenzene	1
o-cresol	1
bis(2-chloroisopropyl) ether	1
m&p-cresol (coelute)	1
Hexachloroethane	1
n-Nitroso-di-n-propylamine	1
Nitrobenzene	1
Benozic acid	1

TABLE 6-2. PROPOSED CONTAMINANTS OF CONCERN FOR TDH AQUATIC LIFE SURVEY PROGRAM (CONTINUED)

Semi-Volatile Organic Compounds:	**(ppm)**	**Metals:**	**(ppm)**
Isophorone	1	Arsenic	0.04
Bis(2-chloroethoxy)methane	1	Copper	0.4
1,2,4-trichlorobenzene	1	Lead	0.4
Naphthalene	1	Mercury	0.02
4-chloroaniline	1	Zinc	0.4
Hexachlorobutadiene	1		
2-Methyl naphthalene	1	**Pesticides:**	**(ppb)**
1,2,3,5-Tetrachlorobenzene	1	DDT	10
Hexachlorocyclopentadiene	1	DDD	10
2-Chloronaphthalene	1	DDE	5
Total nitroanilines	1	Aldrin	2
Acenaphthylene	1	Dieldrin	6
Dimethyl phthalate	1	Endrin	6
2,6-Dinitrotoluene	1	Chlordane	10
Acenaphthene	1	Heptachlor	2
Dibenzofuran	1	Heptachlor Epoxide	4
2,4-Dinitrotoluene	1	Methoxychlor	30
Fluorene	1	Toxaphene	100
4-Chlorodiphenyl ether	1	Hexachlorobenzene	2
Diethyl phthalate	1	Malathion	20
n-Nitrosodiphenylamine	1	Ethyl Parathion	10
Diphenyl hydrazine	1	Methyl Parathion	10
4-Bromodiphenyl ether	1	Diazion	10
Hexachlorobenzene	1	Chloropyrifos	10
Phenanthrene	1	Endosulfan	10
Anthracene	1	Endosulfan sulfate	10
Di-n-butyl phthalate	1	Alachlor	8
Fluoranthene	1	Dacthal	3
Pyrene	1	Alpha BHC	2
Bis (2-ethylhexyl) adipate	1	Beta BHC	2
Butylbenzl phthalate	1	Delta BHC	2
Benz(a)anthracene	1	Lindane	2
Chrysene	1		
Bis (2-ethylhexyl) phthalate	1	**PCBs**	**(ppb)**
Di-n-octyl phthalate	1	Aroclor 1016	40
Benzo(b)fluoranthene	1	Aroclor 1221	40
Benzo(k)fluoranthene	1	Aroclor 1232	40
Benzo(a)pyrene	1	Aroclor 1242	40
Indeno(1,2,3-cd)pyrene	1	Aroclor 1248	40
Dibenzo(a,h)anthracene	1	Aroclor 1254	40
Benzo(g,h,i)perylene	1	Aroclor 1260	40
		Aroclor 1262	40

Chapter 7

Freshwater Inflow And Bay Circulation

Priority Problem

Adequate seasonal inflow of high quality fresh water into the Galveston Bay Estuary is critical for the survival of most estuarine species and is therefore vital to the maintenance of biodiversity within the estuarine system. Despite this fact, few assurances exist to provide for fresh water resources necessary to maintain estuarine health and productivity. Rather, inflow to Galveston Bay is now dealt with on a case-by-case advocacy process presided over by the Texas Natural Resource Conservation Commission (TNRCC). To ensure that the freshwater inflow requirements of the estuary are met, the management of freshwater inflow on a comprehensive watershed basis is recommended.

Tools for determining the amount, quality, and timing of inflow required to maintain biological productivity and diversity in the Galveston Bay Estuary are being developed as a part of studies mandated by the Texas legislature. This effort is scheduled for completion by February, 1995. Pending completion of these ongoing studies, it is recommended that flexible management targets for freshwater inflow be established, and that Galveston Bay inflow requirements be given high priority in the watershed water allocation process. Further improvement of freshwater inflow management can be achieved by optimal routing of return flows and the conservation of water on a Galveston Bay watershed basis.

Management Goals and Objectives

Task Force members established the following high-priority management goals:

- At a minimum, maintain freshwater inflow to ensure maintenance of ecosystem conditions at present levels and
- If feasible, maintain freshwater inflow at levels that will enhance selected populations and communities identified by the Species Population and Habitat Protection Task Forces

These initial management objectives were further modified and are now the four freshwater flow (FW) objectives and seven FW actions set forth in the Galveston Bay Plan:

Objective 1	Determine annual and seasonal inflow needs to the bay by 1995
Action FW-1.	Complete current studies to determine freshwater inflow needs for the bay
Action FW-2.	Expand stream flow, sediment loading, and rainfall monitoring
Objective 2:	Incorporate inflow needs in regulatory authority and planning processes by the year 2000
Action FW-3.	Establish management strategies for meeting freshwater inflow needs
Action FW-4.	Establish inflow regulations to protect ecological needs of the estuary
Action FW-5.	Explore means of providing sediment to the estuary
Objective 3	Increase water use efficiency within the Galveston Bay Program area by 10% by the year 2005
Action FW-6.	Reduce water consumption
Objective 4	Complete an evaluation of bay circulation patterns and their effects on bay habitats and species by the year 1999
Action FW-7.	Evaluate the effects of channels and structures on bay circulation, habitats, and species

Data Information Needs

Task Force members agreed to use the results of the Texas Water Development Board's (TWDB) TXEMP model, a freshwater inflow-biological resources optimization model, to determine the quantities and timing of freshwater inflows needed to maintain current abundance's of selected biological resources.

The goal of Plan Objectives 1, 2, and 3 is to establish and ensure beneficial freshwater inflows necessary for a salinity, nutrient, and sediment loading regime adequate to maintain the productivity of the Bay. Information needed to assess these management objectives include:

- Identification of indicator parameters for freshwater inflows,
- Status and trends in the quantity, location, and timing of freshwater inflows,
- Status and trends in the magnitude and distribution of water quality parameters for freshwater inflows.

Freshwater inflow data are needed to gain a fundamental understanding of how Galveston Bay works. The status and trends in the quantity and timing of freshwater inflow are needed to characterize the freshwater inflow to the Bay. The status and trends in the magnitude and distribution of water quality parameters are needed to assess the physical and biological effects the freshwater inflow regime may have on the Bay. Freshwater inflow data will be used to evaluate the strength of the relationship between the volume and timing of freshwater inflow and:

- Local and bay-wide water quality,
- Abundance of selected species, and
- Quantity and quality of selected habitats.

Task Force members identified candidate indicator parameters to assess the quantity and timing of freshwater inflows (Table 7-1). Direct measurements of freshwater inflow volume are highly recommended; precipitation, land use, and run-off coefficients are required to estimate freshwater inflow volumes where direct measurements are not available. Input parameters to TWDB's TXEMP model were also identified as key information needs in developing water quality parameters.

The goal of Plan Objective 4 is to ensure that alterations to Bay circulation do not negatively affect Bay productivity. Information needed to assess this management objective include:

- Identification of indicator parameters for circulation,
- Descriptions of large-scale circulation patterns.

Depth related temperature and salinity (conductance) measurements are needed to identify distinct water masses. Current meters may be used to measure the speed and direction of these water masses.

A primary purpose of Plan Objectives 1 through 4 is to ensure conditions in the Bay will maintain and enhance Bay species. Information on the status and trends in abundance and distribution of species whose existence depends on specific freshwater flow regimes is required to assess whether freshwater flow controls are having the desired effect on animal populations.

TABLE 7-1. PARAMETERS USED AS INDICATORS OF FRESHWATER INFLOW QUANTITY AND QUALITY.

Candidate Parameters	
Inflows - In areas with gauging stations	
• Tidal flow	
• Freshwater flow	Volume, timing, location
Inflows - In areas without gauging stations	
• Precipitation	
• Runoff coefficients	
Inflow Water Quality	
Insitu Measures	
• Temperature	
• Conductance	
• pH	
• Dissolved Oxygen	
• Turbidity	
Analytical Samples:	
• Oxygen demand, BOD (5-day)	
• TSS, VSS	
• Nutrients:	
Nitrogen - NH_3-N, nitrate, nitrite,	
Phosphorous - Total and ortho-	
• Carbon - TOC	
• Fecal coliform	
• Total/dissolved metal COCs	
• Organic toxic COCs	
• Pesticide COCs	
• Ambient toxicity	

Monitoring activities must provide information to evaluate whether progress toward these management objectives is being made. The freshwater flow component of the regional monitoring program must provide data to assist in:

- Determining whether severe alterations in freshwater inflow are occurring,
- Ascertaining whether severe changes in freshwater inflows may cause alterations in aquatic populations and habitats, and
- Evaluate alternative actions to mitigate identified adverse impacts due to alterations in freshwater inflows in Galveston Bay.

The following monitoring objectives have been used to design the regional monitoring program for Galveston Bay:

- Improve and maintain a system for accurately monitoring freshwater inflow to the Galveston Bay. This information will be evaluated for trends in timing and flow volume.
- Evaluate status and trends of and to make biennial water quality assessments, based on TNRCC segmentation schemes, of Tier One and Tier Two water quality parameters in Bay watersheds.
- Characterize the distribution and trends of parameters (salinity, temperature) selected as indicators of freshwater impact in the Bay,

Assessments of freshwater flow will be based on the weight of evidence from several indicator parameters. From identified Plan objectives and information needs, it is clear that the freshwater flow and bay circulation component of the regional monitoring program must provide local and bay-wide status and trend data.

Programmatic Monitoring

Programmatic monitoring is necessary to fully assess the effectiveness of Plan actions. It is the primary assessment tool for several plan actions and is less critical for other actions. Proposed programmatic monitoring activities are highlighted below.

For actions FW-1, 2, 5, and 7 only administrative monitoring functions are recommended. For action FW-3 activities of the TNRCC will be monitored with respect to the development strategies to assure a consistent inflow management plan. Action FW-4 will monitor the regulatory status of inflow for any legislative changes in authority. Activities for these actions are not expected until 1999. Action FW-6 calls for the reduction of water consumption through a long-term strategy of water conservation. The Program will work with all identified groups to develop a methodology for monitoring water use in the watershed.

Environmental Monitoring

The Monitoring Work Group does not recommend the addition of new elements to current monitoring elements. The Work Group does recommend evaluation and expansion of the role of several important data collection efforts. Results from the TWDB/TPWD modeling efforts to characterize inflow needs to Galveston Bay will be used to make modifications to monitoring activities. This model considers nutrient and sediment requirements, salinity restrictions and fishery productivity to produce a predicted freshwater need to maintain desired levels of biological productivity and diversity. These inflow requirements will be used to provide target numbers for use in future management of freshwater inflow.

Currents

There are no ongoing programs for recording currents in the bay. The COE and other agencies have had short-term current monitoring efforts usually to assess the potential effects of proposed projects on bay circulation. The TWDB operates 5 permanent continuously recording probes for collection of data to support their modeling programs for circulation and salinity and analyses of the relationship between salinity and freshwater inflow in the bay. Assessing currents will not be considered as a monitoring element for the GBRMP. However, the Monitoring Work Group recognizes the need for surveys to assess specific problems associated with bay circulation on a case-by-case basis to enable the determination of any effects of future large-scale projects on bay circulation. The use of USGS doppler methodologies for current surveys has been discussed and will be considered as a monitoring survey program. It is recommended that research efforts be undertaken to provide additional information to characterize the effect of impoundments, dikes, navigation channels, and levees on freshwater inflow to the Bay and circulation patterns within the Bay.

Freshwater Inflow Quantity and Timing

The Monitoring Steering Committee will work with appropriate agencies to improve coordination of monitoring activities to more accurately measure the volume and timing of freshwater inflow at critical locations within the Bay watershed. Estimates of freshwater contributions to the Bay show that the Trinity River watershed accounts for 54% of the freshwater inflow to the Bay. The second highest contributor is the San Jacinto River watershed with 28% and other local watersheds 18%. In deference to the magnitude of these estimates, priority will be placed on improving direct inflow measures for the Trinity and San Jacinto River systems and maintaining capabilities in other systems. Specific improvements identified are the addition of sediment measuring stations, increased numbers of rainfall stations for better inflow estimates in watersheds without flow gauges, and improved accuracy of the rating curve for the spillway at Lake Houston to improve accuracy of San Jacinto River flow.

The primary source of information on freshwater inflow are the USGS gauging stations located in various bay watersheds (Figure 7-1) Several types of flow monitoring stations are operated by the USGS. Some have records of gage-height record only while others are continuous recording stream flow stations. In addition to stream-flow information many of the stations are also water quality stations. Water quality stations may have continuous-recording instrumentation and are sampled routinely by USGS water quality personnel. As described in Chapter 3 the USGS operates four continuous recording monitoring stations for the City of Houston. These stations located on major bayous in the city are continuously monitored for surface water elevation, temperature, conductivity and DO. In addition to these parameters the stations are periodically sampled for a wide range of water quality parameters. The USGS also operates 12 additional stations in the Galveston Bay watershed which can be used to provide information on freshwater inflow.

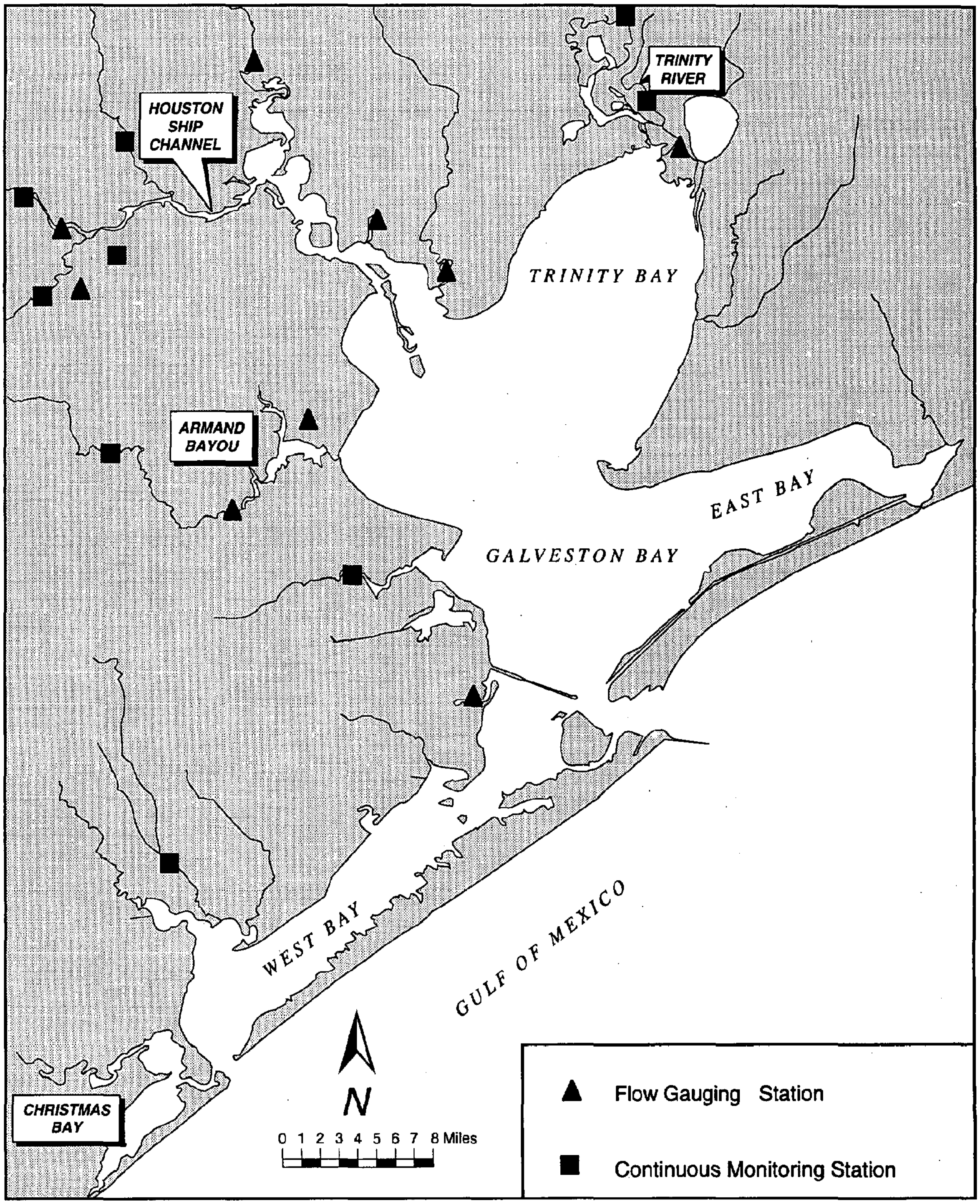


Figure 7-1. USGS flow gauging stations for Galveston Bay inflows.

Steps are currently being taken by the USGS to evaluate the flow measurement capabilities at the Lake Houston spillway. There are concerns for accuracy of this information especially under low flow conditions. An additional flow gauging and water quality station is being constructed by the USGS for evaluation of nutrient loadings from stormwater runoff in Dickinson Bayou (see Chapter 11- Non-Point Sources). With this addition most major inflow contributions will be gauged.

Freshwater Quality

The quality of inflow into the Bay will be evaluated through the integration of efforts of several existing and development programs. The USGS, TNRCC and numerous city and county agencies maintain water quality sampling stations at key locations in the Bay watershed. The state of Texas through the Clean Rivers Program will be conducting biennial assessments of water quality on a basin and sub-basin basis. This information will provide the types of information required to make assessments of water quality and to identify localized problems. A more complete discussion of the relationship between Clean Rivers and the Galveston Bay Program can be found in Chapter 10 - Water and Sediment Quality.

Bay Monitoring

Bay monitoring stations operated as part of the GBRMP will provide information on the effect of freshwater impacts to the Bay. Complete discussion of this program element can be found in Chapter 10 - Water and Sediment Quality. Additional monitoring efforts that have been recommended are the establishment of permanent real-time monitoring stations within the bay. These can be used to supplement the stations currently operated by the TWDB and TPWD.

In addition to water quality parameters other monitoring elements that will provide indirect information on the effect of freshwater impacts include: species population protection and habitat protection.

Chapter 8

Spills/Dumping

Priority Problem

Bay habitats and living resources are impacted by spills of toxic and hazardous materials during storage, handling and transport. The cause of spills are generally evident. Spills may be caused by: tanker collisions, rammings, groundings, and sinkings; human error during transfer operations; and natural catastrophes such as hurricanes, tornadoes or flooding. Several factors must be considered to evaluate the effects of oil spills on the bay. The volume of material released is an important factor in evaluation of potential effect. However, even small amounts of highly toxic materials can have significant impacts. Oil spill response records maintained by the U.S. Coast Guard indicate that, on average, there are two small spills daily of toxic contaminants. Oil alone accounted for over a quarter of a million gallons in 1989. There is usually no cleanup action involved.

Waterborne trash such as cans, bottles, ropes, packing materials, plastic materials (including pellets and post-consumer) or medical wastes are pollutants classified as bay debris. Sources of these types of pollution are 1) materials dumped into rivers or offshore that becomes trapped in the bay, 2) debris from stormwater discharges, and 3) spillage from loading docks. Debris in and around the bay degrades the aesthetics, may cause harm to wildlife, and can cause damage to boats or water intakes. (Morgan and Lee, 1993)

Management Goals and Objectives

Three priority management goals were set forward in The Plan to address the problems identified as part of the characterization phase of the program. These goals are:

- To obtain compensation for environmental injuries,
- To reduce the impact from spills on the natural environment, and
- To eliminate water-borne debris.

To reach these goals the following objectives and action items were identified as steps to help achieve the stated goals. These objectives are:

Objective 1	Support trustee actions to obtain compensation for environmental injuries and ensure that restoration funds are used effectively to benefit the Galveston Bay ecosystem to the maximum extent possible under existing statues and regulations.
Action SD-1	Promote planning to facilitate natural resource damage assessments.
Action SD-2	Identify simplified damage assessment procedures for small oil spills.
Action SD-3	Facilitate effective restoration of Galveston Bay's natural resources injured by spills.
Objective 2	Improve advance planning measures and on-the-ground readiness.
Action SD-4	Facilitate spill cleanup by advance shoreline characterization.
Objective 3	Reduce the amount of shoreline and water-borne debris by half within 5 years.
Action SD-5	Improve trash management near the shoreline.
Action SD-6	Remove trash from stormwater discharges.
Objective 4	Decrease illegal dumping by half within 5 years.
Action SD-7	Publicize environmental harm caused by illegal dumping.

Data Information Needs

The goal of Objective 1 is to improve the mechanisms for obtaining compensation for environmental injury and mitigation of the environmental impacts to habitat and living resources caused by spills in the Bay. Three actions are favored to obtain the maximum benefits available for environmental restoration from the environmental damage assessment process. These actions support pre-spill planning for facilitating initiation of damage assessments, the streamlining of the damage assessment process, and the identification of bay-wide restoration needs.

Objective 2 supports the improvement of advance planning for spill incidents. This is achieved through support for major ongoing developments in spill contingency planning and response preparedness.

Information to assess the achievement of these plan action objectives will be largely programmatic in nature. The primary monitoring programs for habitat, living resources, bay circulation, and water chemistry will provide baseline information on conditions within the bay and will provide information on critical habitats and resources endangered by spills. Supportive environmental monitoring information related to this plan action are:

- Status and trends in areal extent, distribution and quality of existing habitats of concern,
- Status and trends in abundance and distribution of living resources in the Bay,
- Fish and shellfish tissue monitoring for toxics,
- Status and trends, in terms of areal distribution, of water and sediment quality indicators,
- Information on bay circulation and currents.

Each of the monitoring elements which can provide the stated information have detailed descriptions elsewhere in this document. This information can provide baseline information on conditions prior to spill events. These monitoring elements do not however, directly measure the effectiveness of the plan objectives. These objectives are directed at implementation of damage assessment procedures and procedures for implementation of cleanup activities. Development of such procedures will be tracked through programmatic monitoring actions.

Objectives 3 and 4 are directed at achieving reductions in water-borne debris and illegal dumping activities. Informational needs to assess these objectives include:

- Data on the occurrence, magnitude, and distribution, of water-borne debris,
- Information on the occurrence of illegal dumping of trash into the Bay.

Collection of monitoring data to address these data needs is discussed in the environmental monitoring section of this chapter.

Programmatic Monitoring

For this action plan, programmatic monitoring more directly monitors plan objectives than does environmental monitoring. Measures for assessing the effect of Objectives 1 through 4 include:

- Monitoring for adoption of pre-spill planning including, administrative and procedural methods to facilitate timely damage assessments,
- Monitoring for development of simplified damage assessment compensation tables to effect efficient and effective recoveries of damages,
- Bay-wide baseline information on pre-release environmental conditions,
- Monitor to evaluate the presence of adequate waste receptacles at bay marinas, boat ramps, parks, and other public areas, and
- Survey local governments for implementation of measures to remove floating trash and debris from stormwater discharges.

Environmental Monitoring

Data sets made available through the GBRMP monitoring elements for habitat, species and water quality will be integrated geographically. This will be accomplished through GIS technology to provide baseline environmental assessment information, this will be used in advance shoreline characterization, and habitat restoration needs. Each of these programs is discussed in detail in their respective chapters.

Environmental information on debris reduction will be obtained through sponsorship of new debris studies similar to the Galveston Bay debris characterization study (Morgan and Lee, 1993). The objective of this study was to characterize the occurrence, magnitude, distribution and identity of possible sources of debris in the Galveston Bay Estuary. The Galveston Bay Program will be responsible for implementing the survey every three years and will report its findings in the biennial State of the Bay Symposia.

Chapter 9

Shoreline Management

Priority Problem

Galveston Bay shares many problems with other estuaries of a similar stature chiefly in the rapidly escalating demands placed upon its resources because of an expanding population and associated development. Human use and development activities can produce unintended results, such as habitat alteration and destruction, eutrophication, pollution, loss of biodiversity, and extinction of species.

Galveston Bay system is also shaped by human processes as the bay is a resource utilized by many people. People are drawn to the bay area to enjoy the benefits of waterfront living, and access to exploitable natural resources such as fish and wildlife; oil gas and other minerals; industrial activities and agriculture. Human activities can up set the natural balance of the shoreline ecosystem and often inhibit or prohibit natural recuperative abilities of the shoreline.

Continued development of the shoreline contributes to shore erosion, loss of wetlands, increased point and non-point source pollution, and reduced public access to the shore. Shoreline management practices frequently fail to balance the need for public access to bay resources with environmentally compatible development. Specific negative environmental consequences resulting from use of the bay shoreline include: 1) human-induced erosion; 2) water usage, point source, and non-point source impacts; 3) increased water-borne debris; 4) increased heavy metals, fecal coliforms, nutrients, toxic organics, and decreased dissolved oxygen concentrations; and 5) loss of wetlands.

Management Goals and Objectives

Major goals proposed by *The Plan* for shoreline management include the following:

- Reduce negative environmental consequences to the bay, and
- Increase environmentally compatible public access to bay resources.

To accomplish these goals the Shoreline management Task Force developed the following action plan objectives.

Objective 1	Adopt a coordinated ecosystem approach to plan and permit shoreline development by 1996.
Action SM-1	Establish a planning program for shoreline development.
Action SM-2	Identify appropriate residential shoreline development guidelines.
Action SM-3	Identify appropriate commercial and industrial shoreline development guidelines.
Action SM-4	Minimize negative effects of structures and dredging on publicly owned lands.

Objective 2	Increase recreational opportunities and access to the bay by providing facilities such as parks, boat ramps, piers, trails, etc., that do not damage the bay.
Action SM-5	Improve access to publicly owned shorelines.

Data Information Needs

Many impacts to the environment related to shoreline issues are non-point in nature. As such these outcomes are better measured in terms of implementation rather than measurable environmental outcomes. We do recognize that maintenance or improvement in environmental water quality in terms of wetland area and quality, water and sediment quality, and to a lesser extent species populations, can be considered to be an indirect monitoring of the effectiveness of all plan actions.

Three actions, SM-1, 2, and 3, are recommended to establish plans and guidelines that address the environmental impacts of shoreline development activities. Specific negative environmental consequences resulting from bay shoreline use are: 1) human-induced erosion; 2) water usage, point source, and non-point source impacts; 3) increased water-borne debris; 4) increased heavy metals, fecal coliforms, nutrients, toxic organics, and decreased dissolved oxygen concentrations and 5) loss of wetlands. Monitoring for accomplishment of these actions will be both programmatic and environmental in nature. The water quality element of the regional monitoring program can provide some information on trends for parameters listed above. The regional monitoring program is not however, designed to provide information of the type needed to assess site-specific problems.

Action SM-4 is directed at reducing environmental effects of manmade structures that may alter bay circulation, impair existing habitat, threaten water quality and degrade aesthetics. Bulkheads, docks, pipelines, barges, abandoned petroleum structures and other manmade shoreline fabrications are included among such structures. Monitoring for this action will be primarily programmatic in nature.

Programmatic Monitoring

Accomplishments for action items SM-1 through 3 can be monitored through assessments of local authorities for development and implementation of local development regulations consistent with the CMP and *The Plan*. Surveys would include information on residential (SM-1) and commercial and industrial guidelines (SM-3) for shoreline development.

An inventory and removal priority will be assigned to all derelict structures on state-owned lands. Priority will be based on aesthetics, submerged habitat value, threat to shorelines, habitats, water quality, or safety. Many of the actions address reducing the potential for impact. It will be difficult to environmentally assess the effects of such actions. Documentation of actions taken will serve as a level of success of this action. Future periodic surveys for derelict structures can be conducted to assess the effectiveness of this objective.

Shoreline Management Action SM-5 is directed at improving access to bay shoreline for ecologically protective recreational activities. Accounting for increased access will be a programmatic function. The Galveston Bay Program will inventory and map existing access points and will monitor improvements in capacity and increases in access to bay recreational facilities over time.

Environmental Monitoring

The core environmental monitoring programs habitat, species, and water quality will provide information concerning areas with environmental concerns. These areas can be compared to the GLO inventory of derelict structures (SM-4) for potential links to environmental impacts. Continued monitoring will record any improvements, if any as a result of structure removals. Fecal coliform is an example of a key indicator which may be used to evaluate reductions in raw sewage discharges from cabins & houseboats. Monitoring for such localized effects will not be possible through the proposed ambient monitoring program. A monitoring program to document environmental impacts at such local levels can be developed. Additional monitoring stations can be implemented to achieve this but additional information such as location of enforcement activities must be established before this can be done.

The habitat identification element of the monitoring program will also provide important information for documenting and tracking shoreline land use trends (SM-1). Information on land use change will be assessed on a 3-year basis. This information can provide valuable information on shoreline modifications on a large scale. Additional information concerning this program element can be found in Chapter 4 - Habitat Protection.

Chapter 10

Water And Sediment Quality

Priority Problems

Water masses in the bay are important in the transport and mixing of contaminants. Sediments act as the ultimate sink for deposition of those water column contaminants bound to suspended particles. Although the bay is in overall good condition, there are local problem areas which threaten both public health and the ecology of the estuary system. Toxic hot spots, eutrophication, and low dissolved oxygen (DO) levels occur in problem areas suffering from high pollutant/nutrient input and poor circulation/flushing. In these areas, degraded water and sediment quality may result in toxicity, habitat degradation, and low dissolved oxygen levels. A limited number of samples have indicated possible water quality criteria exceedences of organic chemicals DDT and PCBs in HSC and San Jacinto River segments (Ward and Armstrong, 1992). Other studies have suggested possible elevated levels of arsenic, cadmium, chromium and nickel in bay sediments. Efforts to maintain and improve water and sediment quality must address ambient toxicity in the Bay and causes of low DO in certain problem areas.

Management Goals and Objectives

Water and Sediment Quality Task Force members established the following high-priority management goals:

- Attain and maintain concentrations of toxics of concern in estuarine waters and sediments below levels posing unacceptable risks to ecosystem resources and human health

- Attain and maintain levels of dissolved oxygen, at or above water quality criteria

Data Information Needs

The primary goal of the monitoring program is the assessment of the effectiveness of actions in achieving the stated objectives. Long term data information needs to assess these management objectives include:

- Identification of specific criteria to assess water and sediment quality,
- Identification of toxic chemicals of concern (COCs), and information on the magnitude and distribution of COCs in Bay water and sediments,
- Data on the magnitude and distribution of conventional water and sediment quality parameters in Bay waters and sediments,
- Data on the magnitude and distribution of water column and sediment toxicity of Bay waters and sediments, and
- Collection of dissolved oxygen data consistent with requirements for state standards criteria.

Not all chemicals in the environment warrant equal attention. Chemicals of concern (COCs) are a limited set of chemicals that may adversely affect Bay biota and human populations. Identification of concentrations of COCs in Bay waters and sediments are a key information need. Knowledge of the spatial distribution of COC concentrations allows evaluation of water and sediment quality in particular segments of the bay as well as comparisons among different bay segments.

Dissolved oxygen will be directly compared to State of Texas water quality criteria as an indicator of whether environmental levels pose a problem to bay biota. Areas within the bay system found to exhibit variations in DO which may indicate potential problems with meeting state criteria will be monitored with continuous monitoring instrumentation. This will supplement data collected as part of the Tier One DO sampling effort. This data will be used to evaluate diurnal patterns of DO and compliance with state water quality criteria.

Conventional water quality parameters are also needed to (1) interpret responses by Bay biota or (2) infer the relative strength of certain physical processes. For example, salinity may be used to infer the role of freshwater inflow and exchange of Bay and Gulf waters. Nutrient concentrations in bay waters may have an effect on primary productivity within the Bay. Elevated levels can result in algal blooms and eutrophication problems. Conversely, low levels of nutrients can be limiting factors in the bay's overall productivity. Water quality issues related to pathogens were discussed by Water and Sediment Quality Task Force members. Their discussions were incorporated in Chapter 6: Public Health Protection.

Water and Sediment Quality Task Force members also recognized the need for monitoring contaminant sources. Contaminant sources (e.g., point source, non-point source, dredged material) drive the input of potentially toxic substances into the Bay. Task Force members emphasized the need for information characterizing contaminant sources and their relative contribution. However, the regional monitoring effort focuses on characterizing ambient conditions in the bay. Point source NPDES Stormwater Permit compliance monitoring data can be used with regional monitoring data to assess the potential effects these sources may have on bay biota as well as human populations.

Objective 1:	Eliminate ambient toxicity in Galveston Bay water and sediments by 2014
Action WSQ-1.	Reduce contaminant concentrations to meet standards and criteria
Action WSQ-2.	Determine sources of ambient toxicity in water and sediment
Action WSQ-3.	Establish sediment quality criteria
Action WSQ-4.	Perform TMDL loading studies for toxics
Action WSQ-5.	Support Clean Texas 2000 Pollution Prevention Program
Objective 2:	By 2004, ensure that all water quality segments within the estuary are in compliance with established dissolved oxygen standards
Action WSQ-6.	Reduce nutrient and BOD loadings to problem areas
Action WSQ-7.	Perform TMDL loading studies for oxygen demand and nutrients

Programmatic Monitoring

The ultimate measure of success in this element will be measured in environmental terms. However, there are programmatic measures important to the success of the Water Quality element.

Action WSQ-2 calls for the identification of sources of toxicity in water and sediment. Knowledge of the point source loadings to the bay and estimates of non-point sources is essential to evaluate this action. The Program office will obtain and evaluate this information from the TNRCC permit self-reporting information and other sources of information such as TRI data, county permit reporting and sampling data sets. In addition non-point source estimates will be available from NPDES stormwater programs and other monitoring sources.

Action WSQ-3 acknowledges the need for development of appropriate sediment criteria for aquatic life and human health protection. The TNRCC is charged with establishing and adopting such criteria. Progress toward development of these criteria will be tracked and reported by The Galveston Bay Program.

Action WSQ-4 requires the performance of TMDLs (total maximum daily load) for toxics integrating both point and non-point sources into the process. TMDLs are to be performed in water quality segments not meeting standards and areas with a high potential for impact. The Program will compile information on the number of toxic TMDLs performed.

Action WSQ-5 supports the Clean Texas 2000 Pollution Prevention Program. The Program will track participation by bay-area industries and municipalities, and will document significantly successful participants. This can be monitored by surveys directed at measuring participation in the program. Toxic Release Inventory data will be monitored for anticipated reductions in toxic emissions and discharges as a result of this program. Action WSQ-6 calls for the reduction of nutrient and BOD loadings to most sensitive and most impacted areas. The Program will track the process of identifying these areas. In addition The Program will track the reductions in loadings achieved through this initiative.

Action WSQ-7 calls for the performance of TMDL studies for oxygen demand and nutrients accounting for both point and non-point loadings. The Program will track the number of such TMDL studies that are accomplished.

Environmental Monitoring

Monitoring activities must provide information to evaluate whether progress toward management objectives is being made. The water and sediment quality component of the regional monitoring program must provide data to assist in:

- Characterizing the concentration and trends of selected toxics in Bay waters and sediments,
- Characterizing the distribution and trends of toxicity in waters and sediments.
- Characterizing the magnitude, extent, and trends of selected conventional water and sediment quality parameters
- Data to evaluate whether ambient COC levels in water and/or sediment may cause alterations in aquatic populations and habitats,

Furthermore, local compliance monitoring must be conducted concurrently to determine the relative contribution of toxics sources. It is fully expected that regional monitoring program data will be used by those conducting compliance monitoring programs and short-term studies to assess the effectiveness of pollutant source control actions.

Water Column Sampling Program

Geographical Boundaries

The boundaries of the Galveston Bay Regional Monitoring Program are defined as all open-bay areas and tidal portions of tributaries. Open bay and tidal portions are defined as marine waters for criteria application. Marine waters are defined as waters having measurable elevation changes due to normal tides or in the absence of tidal information, waters with salinity's of two parts per thousand or greater in a significant portion of the water column. The Texas Natural Resource Conservation Commission (TNRCC) segmentation scheme designates tidally influenced segments and will be used to define the geographic extent of this program. These are given in §307, Appendix B of the water quality standards document (TNRCC, 1991) .

Water Quality Monitoring Objectives

To make Bay-wide estimations of toxicity in terms of areal extent (±10%). Toxicity shall be defined as Inland Silverside, *Menidia beryllina,* mortality in a 7-day chronic test significantly greater than the control and/or mortality to mysid shrimp, *Mysidopsis bahia,* in a 96-hour acute test is significantly greater than mortality in the control group. Significance is to be determined using a one-tailed Dunnets test with a 95% confidence interval.

To make bay-wide estimates ; in terms of areal extent (±10%), and temporal trend, in terms of areal extent and magnitude, of exceedences in State standards criteria. Criteria evaluated will be human health and aquatic life criteria, as defined in the Texas State Surface Water Quality Standards.

To make bay-wide estimates in terms of areal extent (±10%) and temporal trends, in terms of areal extent and magnitude, those waters in violation of state criteria for dissolved oxygen as defined in the Texas State Surface Water Quality Standards.

To make Bay-wide estimates of the eutrophic condition of waters in Galveston Bay in terms of aerial extent (±10%). Such estimates will be developed from collection of water quality information (nutrients, TSS and turbidity) and estimates of primary productivity from chlorophyll-*a* measures.

Parameter Selection and Data Quality Objectives

Selection of appropriate parameters for inclusion in the ambient water portion of the Regional Monitoring Program was accomplished through review of the established data information needs and monitoring objectives. Beyond those specific parameters needed to assess monitoring objectives, numerous standard monitoring parameters of specific agency and historical importance have been included. Recommendations by those responsible for the review of historical trends (Ward & Armstrong) were also considered. Recommendations from the TWDB which has responsibility for modeling the bay system were solicited (David Brock, TWDB, Personal communication). The Monitoring Work Group conducted this review and established the list of parameters given in Table 10-1. Monitoring for these parameters will allow assessment of the effect of plan actions and establish a better understanding of the Galveston Bay system.

Monitoring for plan actions requires that comparisons be made to toxic criteria. State water quality standards specify criteria for protection of aquatic life and public health concerns. Specific aquatic life numerical criteria have been established and adopted in the state water quality standards document "for those specific toxic substances for which adequate toxicity information is available, and which have the potential for exerting adverse impacts on water in the state" (TNRCC, 1991). Human health criteria have been established "to prevent contamination of fish and other aquatic life to ensure that they are safe for human health consumption". Specific human health concentration criteria for water are applicable to waters in the state which have sustainable fisheries, and /or designation or use as a public drinking water supply. The state standards further states that, "all bays, estuaries, and tidal rivers" are defined as having a sustainable fishery. The Regional Monitoring Program will, where appropriate, evaluate monitoring results against state criteria for both aquatic life and public health protection.

State water quality standards establish both freshwater and marine aquatic life criteria. All open-bay and tidal portions of tributaries, our designated area of interest, are defined by the State as marine waters. Therefore marine criteria will be used for evaluation of analytical results. All parameters having either marine aquatic life and public health protection criteria, or both, have been included in Table 10-2 as the list of COCs for water quality monitoring.

Numerical values for marine, acute and chronic, aquatic life protection have been adopted for inclusion in the state water quality standards. Acute criteria are "applicable to all waters of the state, with the exception of small areas of initial dilution at discharge points". Chronic criteria are applicable to "all waters of the state with designated or existing aquatic life uses, except inside mixing zones and below critical low-flow conditions" (TNRCC, 1991). For purpose of this program comparisons to both acute and chronic criteria will be made.

The lower of the aquatic life or human health criteria will be used to establish appropriate performance criteria for analytical procedures. Where these levels of analytical discrimination are not attainable, minimum analytical levels will be determined. The State defines minimum analytical level as the lowest concentration at which a particular substance can be "quantitatively measured, with a defined precision level, using approved analytical methods" (TNRCC, 1991). Minimum analytical levels are established based on analyses of the analyte in the matrix of concern.

Selected stations will be designated as standards attainment stations for TNRCC segments. Stations designated for standards attainment will be selected by the TNRCC as required by §307.9.a.1 of the State water quality standards. These stations will be sampled four times a year for Tier One and Tier Two parameters.

TABLE 10-1. PARAMETERS AND PERFORMANCE CRITERIA FOR WATER AND SEDIMENT QUALITY.

Ambient Water Column:

Tier One Monitoring Parameter	**Data Quality Objectives**
Insitu Measures	
• Temperature	±0.5 ^{o} Celsius
• Salinity	±0.1 ppt
• Conductivity	umhos/cm, three significant figures
• pH	±0.1 S.U.
• Dissolved Oxygen	±0.1 mg/l
• Turbidity, as Secchi depth	±0.1 meters
• Sample depth	±0.1 meters
• Photosynthetically active radiation	
Analytical Samples:	
• TSS, VSS	±1.0 mg/l
• Oxygen demand, 5-day CBOD (tributary monitoring only)	±1.0 mg/l
• Nutrients: Nitrogen - NH_3-N, nitrate, nitrite,	±0.01 mg/l
Phosphorous - Total and ortho	±0.01 mg/l
Carbon - TOC	±1.0 mg/l
• Chlorophyll-a	
• Fecal coliforms	# colonies/100 ml
Tier Two Monitoring Parameters	
• Water Hardness (for salinity < 2 ppt)	±0.1 mg/l as $CaCO_3$
• Dissolved Metal COCs	ug/l [1]
• Organic toxic COCs	ug/l [1]
• Pesticide COCs	ug/l [1]
• Ambient toxicity	% survival

Sediment Quality Monitoring Parameters:

• Grain size	
• Sediment bound metals	ug/l [1]
• Sediment bound organics	ug/l [1]
• Benthic community assessments	Community index
• Sediment toxicity tests	% survival
• TOC	±1.0 mg/l
• AVS (to be added at later date)	

1 - Data Quality Objectives will be based on the lower of ambient criteria or State defined minimum analytical levels.

TABLE 10-2. CONTAMINANTS OF CONCERN FOR THE GALVESTON BAY REGIONAL WATER QUALITY MONITORING PROGRAM.

Organics

Aldrin (A,H)
Alpha-hexachlorocyclohexane
Benzene (H)
Benzidine (H)
Beta-hexachlorocyclohexane (H)
Bis (chloromethyl) ether (H)
Carbaryl (A)
Carbon tetrachloride (H)
Chlordane (A,H)
Chrlorobenzene (H)
Chloroform (H)
Chlorpyrifos (A)
Cresols (H)
DDD (H)
DDE (H)
DDT (A,H)
Danitol (H)
Demeton (A)
Dibromochloromethane (H)
1,2- dibromoethane (H)
Dieldrin (A,H)
1,2- dichloroethane (H)
1,1- dichloroethylene (H)
Dicofol (H)
Dioxins / Furans (TCDD Equiv.) (H)
Endosulfan(A,H)
Endrin (A,H)
Guthion (A)
Heptachlor (A,H)`
Heptachlor epoxide (H)
Hexacholrobenzene (H)
Hexachlorobutadiene (H)
Hexachlorocyclohexane(Lindane) (A,.H)
Hexachloroethane (H)
Hexachlorophene (H)
Malathion (A,H)
Methyl ethyl ketone (H)
Methoxychlor (A)
Mirex (A,H)
Nitrobenzene (H)
n- Nitrosodiethylamine (H)
n- Nitroso-di-n-butylamine (H)
Total PCBs (A,H)
Parathion (A)
Phenanthrene (A)
Pentachlorobenzene (H)
Pentachlorophenol (A,H)
Pyridine (H)
1,2,4,5- Tetrachlorobenzene (H)
Tetrachloroethylene (H)
Toxaphene (A,H)
2,4,5- Trichlorophenol (A)
Vinyl chloride (H)
Total petroleum hydrocarbons

Inorganics

Aluminum (D,A)
Arsenic (D,A)
Cadmium (D,A)
Chromium III (D,A)
Chromium VI (D,A)
Copper (D,A)
Cyanide (A)
Lead (D,A,H)
Mercury (D,A,H)
Nickel (D,A)
Selenium (D,A)
Silver, as free ion (D,A)
Tributyltin (A)
Zinc (D,A)

(D) Dissolved portion.
(A) Texas Aquatic Life Criteria Parameter. Criteria are based on ambient water quality criteria documents published by USEPA.
(H) Texas Human Health Criteria Parameter. Concentration in marine waters to prevent contamination of fish and other aquatic life to ensure that they are safe for human consumption.

Spatial Design and Statistical Resolving Power

Integration of information from multiple sources on the various resources of Galveston Bay, especially water and sediment quality, was determined to be a critical function for successful system-wide sampling. Two distinct sampling environments have been used in design of the Regional Monitoring Program. They are classified as open-bay and tidally influenced stream segments. Classification designations have been adopted from Section 307, Appendix A. of the State Surface Water Quality Standards document. The adoption of a common sampling design agreed to by all participants in the regional monitoring effort will greatly contribute to this integration effort. Two separate spatial strategies were adopted for bay and tidal segments.

Open-Bay Monitoring

Several potential spatial strategies were evaluated by the Monitoring Work Group. These included randomized sampling, stratified random designs and a probabilistic sampling model such as the one used in the USEPA Environmental Monitoring and Assessment Program (EMAP). The spatial design model adopted for the open-bay water portions of the Regional Monitoring Program is a probability-based, hierarchical grid design developed and first implemented by the EPA's EMAP. The design uses probability sampling theory to provide rigorous, unbiased estimates of environmental conditions. EMAP stated goals and objectives (U.S. EPA, 1992b) were determined to be consistent with our own:

- Estimate the current status and trends in the condition of ecological resources within a defined spatial scale, with known statistical confidence; and
- Seek associations among anthropocentric stress and ecological conditions; and
- Provide periodic statistical summaries and interpretive reports on ecological status and trends to resource managers and the public.

Recently conducted R-EMAP projects, including one in Galveston Bay in 1993, have demonstrated the utility of the grid structure in addressing any spatially distributed and well defined ecological resource. In addition, this approach has been successfully applied to several estuary monitoring programs including the Delaware Bay, Tampa Bay and Sarasota Bay National Estuary Programs. In the opinion of the Work Group this design had numerous advantages over other considered designs. Those advantages include:

- Significant research and field validation efforts have been conducted to make the sampling design statistically valid and defensible,
- A probability based sampling design is free of subjectivity and site selection bias,
- A grid insures that the samples are evenly distributed over the spatial extent of the resource. This allows the development of distribution functions based on areal extent,

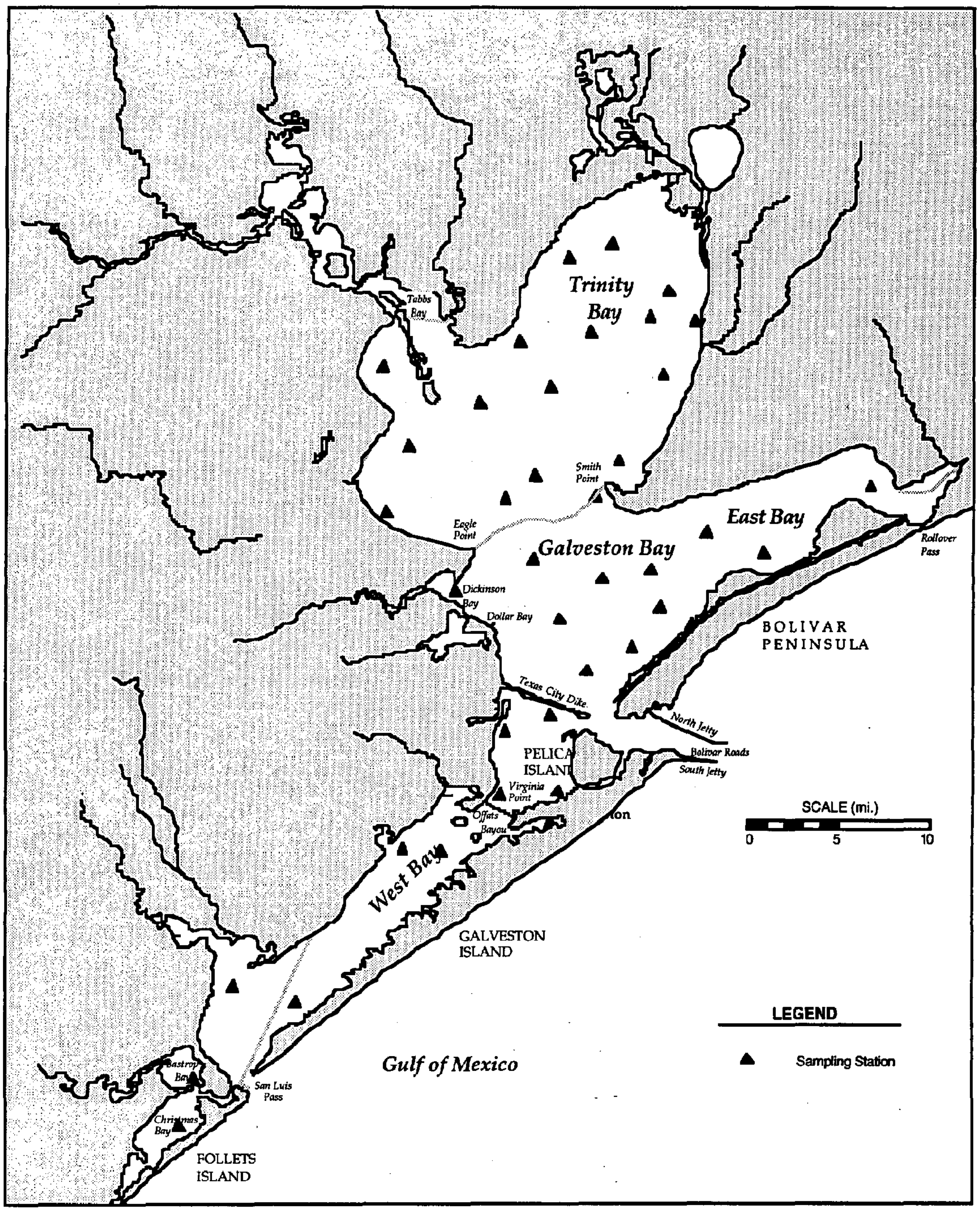
- It has been demonstrated that historical sites, of the sort sampled for years by resource agencies, can be incorporated into the regional plan and still maintain statistical validity,
- Estimates of indicator values in terms of areal extent can be made and the uncertainty associated with the estimate can be determined (e.g. 90% ±10% of Galveston Bay meets sediment criteria levels),
- The types of estimates that can be made (i.e. areal distribution) are more easily understood by non-technical managers and the public,
- The data can be grouped or sub-divided numerous ways and estimates of uncertainty can be made with known levels of confidence.

With the stated level of uncertainty and desiring to make annual estimates, sample site selection was made by randomly placing a 4-fold enhancement of the EMAP grid structure over the Galveston Bay area. The result is hexagons of approximately 70 km^2 with a 7.5 km distance between the grid centers. From each hexagon which included any part of the defined area, a single station was randomly selected. If the sample point fell on land or outside of the defined sampling area it was thrown out. The sample selection process was repeated four times to provide four sets of sampling stations (Appendix C). The result is an average of 34 stations per year. The program has the option of sampling the same set of stations each year or a new set each of four years before revisiting a site. Sampling the same stations each year will increase trend detection capabilities but will also increase the uncertainty in the ability to make statements based on areal extent. Conversely, if a new set of stations is visited each year, with a subset revisited to enhance trend detection, long term trend detection capabilities are reduced, but the 10% uncertainty of areal extent is upheld. A final decision on this detail of the program has not been made pending results of the first year sampling. The program will be implemented with the first year set of stations which are represented by Figure 10-1.

The Regional Monitoring Work Group acknowledges Dr. Kevin Summers of the EMAP-Estuaries program in Gulf Breeze, Florida, who provided the technical assistance for development of the Galveston Bay Regional Monitoring Program probabilistic sampling design.

Tidal Streams

Monitoring tidal stream segments, including the Houston Ship Channel, and upstream segments is a second element in the Regional Monitoring Program. Data gathered from this monitoring element will provide information on inflow loadings of COCs to the bay system and will be used as appropriate in assessment of plan objectives. Tributary sampling design will utilize current sampling efforts conducted by monitoring entities. The program has designated five stream basin areas for development of tributary monitoring stations. The two major river basin watersheds for the Galveston Bay system are the San Jacinto and lower Trinity River systems. These two watersheds provide an estimated 82% of the freshwater inflow to Galveston Bay. Other designated basins are the upper Houston Ship



SOURCE: EPA, 1994

Figure 10-1. Galveston Bay Regional Monitoring Program Ambient Water and Sediment Quality Sampling Stations

Channel drainage basin, Clear Lake-Clear Creek basin, Dickinson Bay basin and Chocolate Bay basin. Adoption of comparable sampling and analytical methods will allow creation of a regional database incorporating data from all local and state agencies sampling in these basins. Figures showing the distribution of sampling programs in these tributary systems are found in Chapter 3. This effort is being closely coordinated with the Texas Clean Rivers Program to ensure comparability with open-bay sampling. Clean Rivers is a state program administered locally by the Houston-Galveston Area Council. The Texas Clean Rivers Act was passed by the legislature in 1991. Clean Rivers seeks to provide coordinated river basin assessment information utilizing a watershed management approach. Close coordination with the Clean Rivers Program will assure a truly regional monitoring program which will include the entire lower Galveston Bay watershed.

Temporal Sampling Strategies

To define monitoring frequencies water quality parameters are divided into two tiers. Tier One parameters will be monitored at a minimum frequency of quarterly. Quarterly samples will be collected during fall (October-November), winter (January-February), spring (April-May), and summer (August-September). For Tier Two parameters sampling will be done on a minimum of annually with many being sampled twice a year. Select Tier Two parameters such as pesticides will be sampled during high freshwater inflow periods, and in late summer. Tier Two parameters which are sampled only once a year will be sampled during the late summer period. Historically, levels for COCs are higher in late summer samplings.

Volunteer monitoring can be an excellent resource for filling gaps in temporal monitoring coverage at impacted or potentially impacted sites. By utilizing volunteer monitoring there is potential to extend both the temporal and the spatial coverage of the monitoring program. This monitoring program acknowledges that volunteer monitors provide quality data and can contribute much to what we know about Galveston Bay.

Performance Criteria

Performance criteria are defined as levels of environmental change that can be detected by the monitoring design. Two means of detecting change to be utilized in the Galveston Bay Regional Monitoring Program are: 1) estimates, in terms of areal extent, of the bay that meet defined environmental conditions and 2) long term trend detection in terms of concentration. The level of change that can be detected is influenced by several variables. These include the monitoring frequency, the number of samples, the variability of the contaminant, the duration of monitoring and, all too often, cost.

In making estimates of areal extent, a response variable can be classified as exhibiting a binary response when compared to a benchmark level (i.e. water quality criteria levels). For example, if the acute criteria for copper is 16.3 ug/l and a sample result of 8.4 ug/l is found then that sample would be classified as having a positive binary response. Conversely if a sample level of 20.0 ug/l is recorded then a negative response would be entered for that sample. Using such an approach, with a probabilistic sampling design, the proportion of an area meeting this response level can be estimated using the binomial distribution. An advantage of this method over traditional trend detection of concentration changes is that prior estimates of variance are not required.

Estimates of the precision in the response variable can be used to predict the probability of detecting a change. In the binomial distribution the precision of the estimate of the response variable is a function of the sample size. The probabilistic sampling program is then designed by determining the sample size needed to meet the *a priori* conditions of uncertainty desired by the sampling design. The level of uncertainty desired by the GBRMP was to be able to make predictions within 10% on an areal basis annually. With this information a probabilistic sampling design was developed which would meet this stated goal.

Projections of the trend detection capability of the sampling design can be estimated using power analyses. Performance criteria for trend detection were established from projections of power analyses conducted on historical data. Power analyses were conducted to evaluate the ability of the proposed systematic sampling program to detect trends, both within segment and bay-wide. Estimates of the level of detectable difference that can be achieved by the proposed sampling design, require the number of samples and an estimate of the variance of the data. Trends can be projected on a bay-wide or more meaningfully a bay segment basis. By using a systematic sampling design any number of segmentation schemes can be overlaid onto the grid without violating conditions of random selection.

A primary segmentation scheme used in the bay is the TNRCC water quality segmentation system. To evaluate the design capability to detect within segment trends using this scheme, the TNRCC segmentation scheme was superimposed on the probabilistic design. From this a nominal value for the number of stations per segment was set at 5. Since the probabilistic design is done on a bay-wide basis stations are not geographically weighted. Therefore, segments with larger areas will receive a larger proportion of the samples. Estimates of the variance within the data sets were calculated by extracting the most recent 5 year period from the historical data sets compiled by Ward & Armstrong during the characterization phase of the program. The power analyses were conducted using the power analysis function available in the Macintosh based JMP® statistical package developed by the SAS Institute Inc.

Power estimates, of ability to detect minimum differences within segments, were generated for three parameters; TOC, ammonia-N, and total zinc. A more complete discussion of this process is included in Appendix D of this document. As expected, these analyses demonstrated that sample sizes required to meet recommended power criteria of 80 percent are highly variable. Minimum detectable differences from the historical mean ranged from 16% for TOC, 18% for total zinc, and 70% for ammonia-N. It should be stated that the values for variance used in these evaluations will provide conservative estimates of detection levels. In calculating the estimates of variance no consideration was given to the effect of between segment or seasonal effects on variance. General estimates of variance, such as standard deviation, show that when evaluated on a segment by segment basis, variance may be lower or higher than the estimates used in this exercise.

The finding is that the proposed sampling scheme will provide adequate and protective estimates of trend detection which are theoretically acceptable. Evaluations of data collected will be conducted biennially to determine if modifications to the program need to be made. As data from the expanded monitoring effort becomes available additional evaluations of the data will be conducted and determinations will be made as to whether modifications to the sampling program need to be made to enhance trend detection.

Some parameters do not lend themselves to trend detection. As can be seen in Table 10-3 many inorganic toxic parameters are reported at concentrations well below the criteria limits. For example, from Table 10-3, silver had only 2.9% of observations above the reported detection level (DL). For organics, a historical review of data shows that more than 80% of the documented samples are reported with concentration levels below detection levels and most criteria levels are below detection capabilities. From this data no meaningful trend detection can be determined. In these cases trends based on areal extent will be utilized to show areas with contaminants at elevated levels against an established level.

Water Column Sampling Methods

Texas Surface Water Quality Standards (Section 307.9) specify sampling procedures for determining standards attainment. With comparisons to standards criteria being a primary issue in water column sampling the Regional Monitoring Program has been designed to be consistent with these requirements. GBRMP Protocols incorporate clean sample collection methods. Clean sample protocols will be implemented immediately to insure accurate results.

For bacteriological and temperature comparisons, water column sampling involves collecting the sample at one foot below the surface in all cases. However, for some standards parameters (e.g. DO, pH) the appropriate collection depth varies, dependent on the type of water body and criteria. Specific sampling requirements for bays, tidal, and non-tidal flowing streams are given in the Texas Water Quality Standards §307.9.b.2- 3.

All in situ field measures will be collected at every sampling event. For open-bay and tidal stations, a surface to bottom profile of DO, pH, salinity, and temperature shall be obtained. For non-tidal stations a surface to bottom profile of DO, pH,

TABLE 10-3 HISTORICAL CONCENTRATION VALUES FOR DISSOLVED METALS IN GALVESTON BAY. ALL VALUES ARE GIVEN IN ug/L. (from, WARD & ARMSTRONG, 1992)

Parameter	**Criteria** [1]	**# Obs.**	% **Obs. >DL**[2]	**Avg. w/ BDL= 0**[3]	**Avg. w/ BDL=DL**[4]
Arsenic	149/78	33	15.2	.71	5.34
Cadmium	45.6/10.0	65	40	.54	1.47
Copper	16.3/4.4	80	47.5	1.78	5.73
Lead	140/5.6	80	38.8	3.5	4.73
Mercury	2.1/1.1	62	71	.59	0.65
Nickel	119/13.2	70	47.1	6.02	9.8
Selenium	564/136	35	0	0	5
Silver	7.2/0.9	35	2.9	.46	18.7
Zinc	98/89	78	91	18.8	19.3

1 Marine Acute/Chronic Criteria.

2 Percent of observations reported as greater than detection limit (DL).

3 Average concentration using 0 as value when below DL (BDL) is reported.

4 Average concentration using DL as value when <DL reported.

conductivity, and temperature will be obtained. Vertical (depth) profiles will be collected according to Section 3.5 of the TNRCC Water Quality Monitoring Procedures Manual. Secchi depth and light penetration will be recorded.

Samples collected for Tier One analytical parameters, will be collected as grab samples at a depth of one foot. Tier Two samples will consist of samples for toxic inorganics and organics. Sampling methods for these parameters will incorporate the use of practical clean method precautions in sampling and analytical procedures. Further development of clean methods will be pursued. Tier Two samples for standards attainment for aquatic life criteria shall be collected at a depth of one foot. The use of a bucket for this sampling is not recommended because of the possible inclusion of the surface layer. This layer may contain sufficiently elevated concentrations of trace metals; or organic compounds that could influence the overall concentration for the sample. For these samples the collection method for the one-foot depth should minimize the contribution of this surface layer. Direct bottle filling from under the surface should be employed for Tier Two samples. Tier Two organics collected at designated standards attainment stations will be collected as a vertical composite from the surface to the natural bottom. Specific sampling procedures can be found in the *Protocols for Sample Collection and Analysis: Galveston Bay Regional Monitoring Program* (Tetra Tech, 1994b).

The GBRMP will identify areas at high risk for DO impacts through its Tier One monitoring effort. Once high risk areas are identified continuous 24-hour monitoring consistent with state DO criteria will be conducted to determine compliance with state DO criteria. These sampling requirements are outlined in §307.9(d)6 of the Texas surface water quality standards. These monitoring activities will support results from plan actions designed to improve DO levels through reductions in nutrient and BOD loadings.

Water Column Analytical Methods

There is a great deal of experience in monitoring most in situ and Tier One parameters. For this reason the methods recommended are those which are currently employed by the many agencies and organizations involved. DO, pH, salinity/conductivity, and temperature are most commonly measured by probe. Volunteer monitoring groups do not have access to probes but do follow a formal Quality Assurance Project Plan (QAPjP) (TNRCC, 1993) utilizing approved protocols from *Standard Methods*. No specific requirements are required beyond the ability to meet the minimum data quality objectives listed in Table 10-1. Monitoring entities should follow their own monitoring protocols or manufacturers recommendations for probe maintenance and use.

Methods as listed in Table 10-4 will be selected based on their ability to provide the lowest practical detection levels. Current analytical capabilities, for metals, by participating laboratories are limited to Atomic Absorption (AA) Furnace methods. The US EPA Region 6 Laboratory is adding inductively coupled plasma - mass spectrometry (ICP-MS) instrumentation (D. Stockton, U.S. EPA - Region 6 Laboratory, Personal communication) and the program will work with them to make these capabilities available for our sampling effort.

Water Column Quality Assurance and Quality Control

All samples will be collected according to *Protocols for Sample Collection and Analysis: Galveston Bay Regional Monitoring Program*. This document specifies collection procedures, container requirements and preservation requirements for proper sample quality assurance. In addition to this document the Galveston Bay Program will coordinate an annual training workshop to provide additional standardization of sample collection procedures.

The ability to determine metals at ambient water quality criteria levels requires the use of stringent quality control procedures to avoid contamination and ensure validity of analytical results (U.S. EPA, 1994). Improved sampling methods must be developed to assure that trace metals determinations are not influenced by contamination during the sampling process.

Quality control specifications for water analyses have been incorporated into state law (Texas Surface Water Quality Standards § 319.1- 319.12). Although originally designed to satisfy National Pollution Discharge Elimination System (NPDES) monitoring programs these requirements, shown in Table 10-5, are equally appropriate for ambient water quality evaluations. This program specifies type and frequency of quality control measures to be run on sample sets. Control measures include blanks, duplicates, spikes and standards. All laboratories conducting analyses for the Galveston Bay Monitoring Program will utilize these QA/QC measures. Additional quality assurance for participating laboratories will come from participation in extramural quality control programs.

A number of commercially available programs are currently utilized by agency labs. One such program available to all laboratories participating in the Regional Monitoring Program is the USEPA Water Pollution Evaluation Study. This program consists of a series of samples shipped to the study participants every six months. Each set includes samples for demands (TOC and CBOD), nutrients (NH3-N, nitrate, ortho and total phosphorous), trace metals, and organics (PCB's, pesticides, volatiles, and aromatics). These results are evaluated against true values and are made available to both the laboratory and the State. Participation in this or other equivalent programs is required at a minimum frequency of twice per year with quarterly evaluations recommended. The GBRMP recognizes QA/QC procedures outlined in the TNRCC Texas Watch QAPjP (TNRCC, 1993) for volunteer monitoring data.

TABLE 10-4. COMPARABLE AND ACCEPTABLE ANALYTICAL METHODS FOR THOSE PARAMETERS TO BE CONDUCTED BY LABORATORY ANALYSES.

Parameter	EPA Method	Standard Methods	Other
TSS	160.2	2540 D	
VSS	160.4	2540 E	
CBOD5	405.1	5210	
NH3-N	350.1*, 350.3	4500-NH3 D,F,H	
Nitrate- nitrite	353.1,353.2*, 353.3	4500-NO3 C,D,E,F	
Phosphorous (all types)	365.1, 365.2. 365.3, 365.4	4500-P D,E,F	
Total Organic Carbon	415.1	5310 B,C	
Chlorophyll-a		1002.G.2	TNRCC
Fecal coliforms		9222 D	
Water hardness	130.1, 130.2	2340 C	
Dissolved metals	AA Furnace, ICP-MS	3113 B	
Mercury	245.1, 245.2, 245.5 (Sediment)	3500 Hg-B	
Volatile organics	624,1624	6220 B	
Acid-base Neutral Organics	625, 1625	6410 B 6440	
Pesticides	608, 625	6410 B 6630 B,C	

* Recommended Method in U. S. EPA Monitoring Guidance for the National Estuary Program.

TABLE 10-5.REQUIRED QUALITY CONTROL ANALYSIS FOR GALVESTON BAY REGIONAL MONITORING PROGRAM.

Parameter	Blank	Standard	Duplicate	Spike
Bacterial	A		B	
Alkalinity		A	B	
Ammonia Nitrogen	A	A	B	B
BOD	A	A	B	
BOD-Carbonaceous	A	A	B	
COD	A	A	B	B
Chloride	A	A	B	B
Chloride-Total or Free		D		
Cyanide-total or Ammenable to Chlorination	A	A	B	B
Fluoride	A	A	B	B
pH		C		
Kjeldahl Nitrogen	A	A	B	B
Metals (all)	A	A	B	B
Nitrate Nitrogen	A	A	B	B
Nitrite Nitrogen	A	A	B	B
Oil and Grease	A	D		
Orthophosphate	A	A	B	B
Oxygen (dissolved)		A	B	
Phenols	A	A	B	
Phosphorus-Total	A	A	B	B
Specific Conductance	A	A		
Sulfate	A	A	B	B
Sulfide	A	A	B	
Sulfite	A	A	B	
TOC	A	A	B	B
TSS	A		B	
TDS	A	A	B	
Organics by GC or GC/MS	A	A	E	E

A - Wherever specified, at least one blank and one standard shall be performed each day that samples are analyzed.

B - Wherever specified, duplicate and spike analyses shall be performed on a 10% basis each day that samples are analyzed. If one to 10 samples are analyzed on a particular day, then duplicate and one spike analysis shall be performed.

C - For pH analysis, the meter shall be calibrated each day that samples are analyzed using a minimum of two standards which bracket the pH value(s) of the sample(s).

D - For the oil and grease analysis and chlorine-total or free analysis, standards shall be analyzed on a 10% basis. If one to 10 samples are analyzed in lieu of standards for the oil and grease analysis and chlorine-total or free analysis.

E - For GC and GC/MS analyses, duplicate and spike analyses shall be performed on a 5% basis. If one to 20 samples are analyzed in a month, then one duplicate and one spike analysis per month shall be performed.

Source: Texas Surface Water Quality Standards - Sections 319.1 - 319.12

Marine Sediment Quality

Estuarine sediments represent an important habitat for many commercially, recreationally, and ecologically important organisms. Sediments also represent the ultimate sink for many chemical toxics in the estuarine environment. Sediment quality monitoring will provide information to characterize the condition of the aquatic environment, evaluate potential stresses to aquatic and sediment-dwelling organisms, and track habitat recovery following environmental interventions.

Sediment Quality Monitoring Objectives

General sediment monitoring objectives and goals have been previously stated in the introduction to this chapter. Specific sediment quality monitoring objectives are as follows:

To make Bay-wide estimations of sediment toxicity by areal extent (±10%). Where toxicity is defined as Inland Silverside, *Menidia beryllina*, in a 7-day sediment elutriate exposure test are shown to be significantly greater (p=0.05) than those seen in the control and/or where mortality to *Mysidopsis bahia* in a 96-hour sediment elutriate test significantly exceeds (p=0.05) mortality seen in the control group.

To make Bay-wide estimates of areal extent (±10%) and temporal trends, in terms of areal extent and magnitude, for potential biological effects resulting from sediment concentrations greater than the median effect values as published by Long and Morgan (1990). (These evaluations will be made utilizing adopted sediment criteria when they become available.)

To make Bay-wide estimates of areal extent (±10%) and temporal trends in terms of areal extent of sediment benthic evaluations which show degraded benthic communities.

Parameter Selection and Data Quality Objectives

Candidate measures for sediment monitoring were selected to address the management objectives outlined previously in this chapter. Information is needed to assess the trends in concentrations in sediments and the possible effect of these concentrations on living resources. A triad approach to sediment evaluation was selected. This approach utilizes contaminant concentration, toxicity and benthic community evaluations to establish the overall condition of sediment quality.

Estimations of areal extent for toxic COC's requires establishment of a reference level of contaminants that have the potential to cause biotic effects. Since sediment criteria are not available for this evaluation, the Monitoring Work Group has recommended the use of levels published by Long and Morgan (1990), as criteria to assess potential degradation from chemical contaminants (Appendix C). There are two concentration levels at which biotic effects are hypothesized. One level is the hypothesized concentration level at which a biotic effect was seen in 10% of the samples. The second level is the mean concentration at which a biotic effect was seen. These are the same criteria used in the USEPA EMAP program to assess potential for sediment degradation in the Louisianan Province which includes the Texas Coast. Consistent with the EMAP monitoring program, all values above the median values associated with biotic effects (Long and Morgan, 50% effects) will be assessed as representative of sediment degradation. Evaluations using the 10% concentration levels will be conducted to identify areas of potential concern.

Performance Criteria

Trend analyses were conducted on historical data from Galveston Bay (Tetra Tech, 1994) . To provide a range of expected program performance, the power analysis was performed using three contaminants: one with the highest variability (CV=501%), one with the least variability (CV=32.6%), and one with a typical level of variability (CV=138%). For each contaminant, residuals from a simple linear regression were used to estimate the parameters of a two parameter log normal distribution of concentrations, and a random number generator was used to generate a series of random concentrations from this distribution. A trend of known magnitude was then added to the random sequence of concentrations to simulate data collected by a monitoring program of a specified length and number of sampling stations. The simulated data were then tested for the presence of a trend using a significance level of 5% and the results were recorded. This procedure was repeated 1000 times and the percentage of simulations that correctly identified the trend was recorded as the power of the test.

Simulation tests were conducted to evaluate the effect of the number of stations, sampling frequency, replicate sampling and monitoring program duration on trend detection. This analysis demonstrated two important principles. First, the more samples per segment, the greater the power to detect trends. It also showed that there is a point of diminishing returns in program performance as the number of stations increased. Any gains in the ability to detect smaller trends due to increasing stations should be weighed against costs. Second, the more variable a contaminant, the more samples required to get an appreciable increase in power. Improving program performance for extremely variable contaminants may not be financially feasible. Rather than to design a program to detect trends of the most variable of contaminants, it is more effective to design a program around contaminants with typical variability. This strategy will ensure an adequate level of trend detection for the majority of contaminants found in the estuary. From these principles it was decided that all further evaluations would be conducted on the variable with typical variability.

The proposed probabilistic sampling plan for sediment will result in approximately 3 samples per segment. As a result the probabilistic sampling design was determined to be adequate and appropriate for meaningful trend detection. Sediment samples will be collected concurrently with water samples whenever possible. Sediment samples will be collected at half of the bay stations annually, approximately 17 stations, so that all stations are sampled every two years. This will raise the uncertainty level on predictions of areal extent for sediment samples. It is not known at this time what the true level of uncertainty will be but it is expected to be within acceptable limits (<20%). This will be determined after the first round of sampling. If the level of uncertainty is not acceptable the sampling program will be modified accordingly.

Temporal Sampling Strategy

Based on the above analyses an annual sampling schedule was determined to be adequate and appropriate for the goals of the Regional Monitoring Program. All sediment sampling will be conducted along with late summer water quality sampling. All sediment analyses: physical, chemistry, toxicity and benthic evaluations will be conducted for each sample.

Toxic Chemicals of Concern

In the absence of sediment criteria, the chemicals of concern for this sampling program will be as consistent as possible with the EPA EMAP program (Table 10-6). This will allow the program to evaluate its results against the EMAP program for variability and provide additional data for overall program evaluation.

Sediment Sampling and Analytical Methods

Sediment samples will be collected from the aerobic layer of the sediment as defined by color, using an Eckman dredge. If the aerobic layer is less than 3 centimeters, the upper 2-3 centimeters will be collected and homogenized. A minimum of three replicate samples will be collected at each station and composited to form the final sample. The same composite sample will be used for sediment toxicity tests and sediment chemistry. A separate sample will be collected for benthic community analyses.

Toxicity of bay sediments will be evaluated using sediment elutriate tests adopted from USEPA toxicity methods. These tests, run by the USEPA Region 6 laboratory for the TNRCC, have been shown to provide valuable information on bay-area sediment quality (T. Hollister, U.S. EPA - -Region 6 Laboratory, personal communication). Both a vertebrate and invertebrate species will be evaluated for their response to exposure to Bay sediments. Marine tests are the 9-day embryo-larval and teratogenicity chronic test for Inland Silverside, *Menidia beryllina*, and the 96-hour acute test for mysids, *Mysidopsis bahia*.. These methods will be evaluated over a two year period to determine if valuable information is being obtained. Tests will be modified or eliminated as indicated from the data review.

The identification and enumeration of benthic macro-invertebrates will be used to characterize benthic communities, assess sediment quality, and assist in predicting potential impacts to bottom-feeding living resources. Benthic macro-invertebrates are important components of the ecosystem and are sensitive indicators of environmental stress. All taxa will be identified and enumerated. Sediment quality will be assessed based on species composition values. Recommended measurements of community structure include: number of individuals, number of species, species dominance, abundance of contaminant-sensitive species, and abundance of opportunistic and contaminant-tolerant species.

Other measures which provide valuable information include depth of aerobic sediment, gain size, TOC, and measures of acid volatile sulfides (AVS). Grain size data is valuable in explaining and identifying potential causes of temporal or spatial variability in benthic communities. The depth of aerobic sediments provides a direct measure of the biologically active zone. AVS has been shown to be of use as a tool for predicting bioavailability of metals in anoxic sediments (DiToro, et al, 1990). AVS analytical capabilities will be developed and utilized, as available, to assess sediment quality.

TABLE 10-6. SEDIMENT CONTAMINANTS OF CONCERN FOR USEPA EMAP LOUISIANIAN PROVINCE SAMPLING.

PAH'S

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(g,h,i,)perylene
Benzo(k)fluoranthene
Biphenyl
Chrysene
C1, C2, C3, C4 Chrysene
Dibenzo(a,h)anthracene
Dibenzothio
C1,C2, C3 -dibenzothio
Fluoranthene
C1-fluoranthpyrene
Fluorene
C1, C2, C3 fluorene
Naphthalene
C1, C2, C3, C4- naphthalene
Perylene
Phenanthrene
C1, C2, C3, C4-phenanthrene
Pyrene
1,2,3-c,d-pyrene
1-methylnaphthalene
2-methylnaphthalene
2,3,5- Trimethylnaphthalene
2,6- Dinethylnaphthalene
1- methylphenanthrene
High Molecular Wt. PAH's
Low Molecular Wt. PAH's
Total PAH's

PCB's

Pesticides

2,4'DDD
4,4'DDD
2,4'DDE
4,4'DDE
2,4'DDT
4,4'DDT
Aldrin
alpha-BHC
beta-BHC
delta-BHC
alpha- chlordane
gamma- chlordane
Dieldrin
Endrin
Heptachlor
Heptachlor epoxide
Methoxychlor
Lindane
Toxaphene
Malathion
Parathion
Diazinon
Endosulfan
Mirex
Total BHCs

Inorganics

Aluminum
Antimony
Arsenic
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Mercury
Nickel
Selenium
Silver
Tin
Tri-butyl tin
Zinc

Chapter 11

Non-Point Sources of Pollution

Priority Problems

The control of non-point source (NPS) pollution, from literally thousands of possible sources is one of the most difficult areas of environmental management. Sources of such runoff include residential properties, agricultural uses, roadways, municipal stormwater runoff and runoff from industrial and commercial properties which can introduce potentially harmful products into Galveston Bay. The intensity of land development and human induced subsidence, which has reduced wetlands, around Galveston Bay intensifies the problem by removing nature's ability to naturally cleanse this runoff as it proceeds to the bay.

It is estimated that over half of the sediment, phosphorous, fecal coliform bacteria, and oxygen demanding substances introduced into the bay system originate from non-point sources (GBNEP, 1994). Only fecal coliforms have been identified as posing an immediate threat to the open bay. There are, however, notable problems in the urbanized bayous and enclosed areas with poor circulation. Water and sediments in marinas are degraded from boat sewage and introduction of dockside wastes from non-point sources. This is exacerbated by poor circulation and has created localized water quality problems. Other specific problems include DO problems in the HSC, fecal coliform exceedences above contact recreation levels in Dickinson Bayou and Clear Creek, high nutrient concentrations and pollutants from local marinas. In general, non-point sources contribute high levels of fecal coliforms to the bay, causing about half of the bay to be closed to oyster harvesting, and polynuclear aromatic hydrocarbons, which accumulate in seafood.

Management Goals and Objectives

The following were established as priority water non-point pollution management goals:

- To reduce urban NPS pollutant loads,

- To reduce industrial NPS pollutant goals,
- To reduce agricultural NPS pollutant loads, and
- To reduce construction NPS loads

To implement programs to reach these goals the following objectives and action plans were developed.

Objective 1:	Establish a regulatory framework for NPS control throughout the entire immediate Galveston Bay watershed within 5 years.

Action NPS-1	Implement stormwater programs for local municipalities.
Action NPS-2	Perform pilot programs to develop NPS best management practices.

Objective 2	Reduce NPS loads from existing development. In particular reduce PAH loadings from non-point combustion sources and to reduce bacterial loadings affecting oyster harvest areas.

Action NPS-3	Identify and correct priority watershed pollutant problems.
Action NPS-4	Establish residential load reduction programs.
Action NPS-5	Correct malfunctioning shoreline septic tanks.

Objective 3	Reduce urban NPS loading from new development Using technically based best management practices. Pollutants of particular interest for open bay waters are fecal coliform bacteria.

Action NPS-6	Implement NPS reduction Plan Program for New Development.
Action NPS-7	Establish Roadway Planning to minimize NPS effects.

Objective 4	Ensure implementation of industrial NPS programs within 5 years

Action NPS-8	Implement NPDES stormwater program for area industries.
Action NPS-9	Prevent degradation of bay waters by known industrial groundwater plumes.

Objective 5	Manage agricultural runoff to satisfy water quality standards within 5 years.

Action NPS-10	Develop inventory of agricultural non-point sources.
Action NPS-11	Coordinate and implement existing agricultural NPS control programs.

Objective 6	Reduce erosion from construction sites to the maximum extent practicable within 5 years.

Action NPS-12	Adopt regional construction standards for NPS reduction.
Objective 7	Limit migration of toxics and nutrients from construction sites within 10 years.
Action NPS-13	Implement toxics and nutrient control practices at construction sites.
Objective 8	Achieve zero discharge from marinas to surface water within 10 years.
Action NPS-14	Require sewage pump out, storage, and provisions for treatment.
Action NPS-15	Require use of marine sanitary chemicals that can be treated in POTWs.
Objective 9	Eliminate the release of harmful materials (paints, solvents, etc.) from marinas and docksides within 10 years.
Action NPS-16	Implement wash down controls and containment measures.

In general, the most effective and economical controls for NPS are land management techniques and conservation measures in rural zones and implementation of technology-based best management practices in urban zones. For this reason this plan seeks to implement best management practices through regulation and public education. It addresses the regulatory activities of local, state, and federal agencies; the need for public awareness campaigns; development of improved dockside and construction site procedures; management of agricultural run-off; and improvements to septic systems.

Data Information Needs

NPS pollutants enter surface waters in a diffuse manner and are transported to the bay by the stream systems, storm drains, or overland flow draining geographic areas. Because of the diffuse and intermittent nature of NPS pollution it is generally not possible to monitor at their point of origin. NPS pollutants cannot easily be measured in terms of effluent limitations.

Environmental monitoring for NPS pollutants in the GBRMP will from necessity be very broad and non-specific in terms of spatial coverage. The tributary and stream monitoring efforts of the GBRMP will include measures of NPS pollutants of concern (TSS, BOD, nutrients). This monitoring effort will assess the combined load from all, point and non-point, sources upstream of the monitoring stations. The ability to measure the effectiveness of program actions through this monitoring effort will be difficult and elusive and can be used only in the broadest context.

An important future source of information concerning NPS pollutants will be the NPDES stormwater permit program. The Storm Water Management Joint Task Force, which includes Harris County, Harris County Flood Control District and the City of Houston, has submitted a Joint permit application to the EPA and is awaiting permit issuance. The Galveston Bay Program will work with permitted entities to gain access to data and information made available through this monitoring program.

Many of the elements of NPS monitoring are common to all of the individual objectives stated for NPS controls. For this reason each objective will not have a separate monitoring discussion. Discussion of the monitoring for non-point sources is summarized below in a generalized, overview format. Much of the monitoring for this element will be programmatic in nature, directed toward implementation of Best Management Practices (BMPs) and other specific management actions.

Programmatic Monitoring

The Plan highlights the specific activities to be carried out in achieving plan actions. The monitoring plan will not attempt to reiterate all of these tracking and participatory obligations to The Program. The specific actions to be taken to measure success of the actions will however be discussed.

Each of the objectives 1, 3, 6, and 7, will require adoption of ordinances, drainage regulations, codes or zoning plans by local municipalities. Intermediate success of these action plans will be measured in terms of adoption of such NPS management plans and the appropriate legal authority. This can be measured through surveys of all local municipalities. Types of information to be obtained in these surveys would include implementation of, regulatory authority for, and enforcement mechanisms for:

- NPS BMP guidance,
- Stormwater management plans,
- Residential load reduction programs,
- Regulations on shoreline septic tanks,
- Reduction plans for new development,
- Policy of incorporating NPS control and prevention measures into roadway planning, construction, maintenance and design,
- Construction standards for NPS reductions,
- Measures to control toxic and nutrient control practices at construction sites, and
- Marina sewage and wash down control and containment measures.

In addressing agricultural NPS loadings the plan also calls for the development of better estimates of agricultural NPS contributions to Galveston Bay and guidance documents for NPS controls. The Program will coordinate with the Texas Soil & Water Conservation Board (SWCB) in an interagency effort to better characterize agricultural NPS pollution. BMPs developed as a result of this effort will be incorporated into the Galveston Bay BMP Performance Document. The Program will work with the SWCB to evaluate the implementation of agricultural BMPs.

Industries will be monitored for their efforts to meet the requirements of the federal storm water permit program and implementation of pollution prevention plans. This information may also be obtained through surveys or may be available through local industrial associations. Actual stormwater discharge contaminant data will be reported through the NPDES permit process and will be available for review and evaluation.

Action NPS-1 calls for the development of stormwater management plans for the watershed area. Current action is primarily directed at the efforts of the Joint Storm Water Task Force (Houston, Harris County, Harris County Flood Control District and Pasadena). This group is charged with meeting the requirements of the federal stormwater permitting program. Future actions will be to monitor any new requirements for smaller municipalities and to track their implementation.

Included in this monitoring effort will be an inventory of all local cities and the status of their stormwater management plans. Cities without plans will be encouraged to develop them. Information on local effectiveness of BMPs and other management plans will be collected by a Technical Assistance Group.

Action NPS-2 will require the monitoring of pilot programs to determine best management practices for new development. Onsite monitoring will be conducted to quantify the effectiveness of implemented practices and to develop a bay-wide BMP performance document. Monitoring will be conducted by Harris County or TNRCC.

In response to Actions NPS-3 & 4, The Program will monitor local agencies for participation in pilot projects and use this information to compile the *Galveston Bay BMP Performance Document.* In addition the Program will maintain and publish its own inventory of NPS concerns in the bay watershed. Sources of information will include the Texas Clean Rivers biennial basin assessment reports, GBNEP NPS loading maps, state 305b reports.

The Galveston Bay Program Office will implement a NPS education program (NPS-4) directed at reducing NPS loadings from residential activities, including lawn and garden activities, household hazardous wastes, automotive fluids and storm sewer dumping. The Program will coordinate with local governments and organizations to inventory activities in this area. Beginning in 1999 the Galveston Bay Program will participate in evaluating the effectiveness of this program through household surveys aimed at measuring changes in household activities as a result of education efforts.

Action NPS-5 will conduct surveys to evaluate the implementation of local ordinances directed at reducing fecal coliform pollution from septic tanks.

Action NPS-6 This program is designed to bring together the current patchwork of regulatory agencies to jointly address the problem of coastal NPS pollution. The lead agency for this action is the GLO. The Program has tracking responsibilities for this action.

Action NPS-7 The Program will work with the Texas Department of Transportation (TXDOT) to organize educational workshops for county highway agencies, municipal public works programs and others regarding NPS control and prevention in roadway planning, design, construction, operation and maintenance. A major emphasis of this action is reduction of TSS loadings. Records of training programs will be maintained by The Program to document this action. The Program will promote demonstration projects and will document through case studies successful implementation of NPS control and prevention measures. Local agencies will be surveyed for adoption and implementation of proven technology.

Action NPS- 8 The Galveston Bay Program will track industry activities in the bay for implementation of stormwater management and pollution prevention plans. The Program will also collect NPS monitoring data from numerous sources to develop NPS loading estimates and estimates of industrial contributions.

Action NPS-9 Potential ground water impacts to the bay will be inventoried. GIS data maps will be created to indicate known sources of groundwater plumes. This information will come from sources such as CERCLA, RCRA, the Leaking Petroleum Storage Tank Program, the Oil Pollution Act and the Clean Water Act.

Activities, including on-site monitoring, to assess BMP effectiveness will be coordinated by the Texas State Soil & Water Conservation Board. Specific activities are outlined in detail in *The Plan.* The Galveston Bay Program will monitor the development of agricultural BMPs for their inclusion into the Galveston Bay BMP Performance Document. The success of this element will be monitored through documentation of agricultural NPS BMP implementation within the watershed. This objective will include development of educational programs.

NPS-14 and 15 Marinas providing moorage to 10 or more vessels will be required, by state regulation; to provide pump-out facilities for marine toilets and pollution prevention plans addressing wash down controls and containment measures. Activities for this action plan are not scheduled until 1999. Mechanisms for measuring compliance with this action have not been established but compliance will be monitored to assess action effectiveness. Programmatic monitoring for this action will include monitoring local municipalities for adoption of NPS ordinances or changes in local drainage regulations, codes and zoning plans. Again, implementation will be judged largely on the level of implementation of BMPs directed at NPS reduction. Monitoring for this element may include examinations of marina facilities for compliance with local or state regulations. Self reporting through surveys sent out to marina owners is another option. Specific details for measuring compliance with this action have not been determined. When local ordinances are implemented a means of monitoring for compliance will be developed.

Environmental Monitoring

Because of the diffuse and pervasive character of NPS pollution, it's intermittent nature and the high levels of variability it exhibits, its would require a tremendous commitment of monitoring resources. The ability of the GBRMP to assess site specific NPS control effects will be limited due to its broad scope. The GBRMP will work closely with the Houston-Galveston Area Council (H-GAC) to coordinate assessment work under the Clean Rivers Program to address nonpoint source pollution from upstream areas within the Galveston Bay watershed. GBRMP stations located at USGS gauging stations will provide some information on loadings to the system. Information of this type will not assess individual activities but will integrate the effects of all activities within a watershed.

Stream monitoring under the GBRMP will monitor for long term trends in nutrients, fecal coliform, DO and TSS and related parameters in the ambient water column. Through cooperation with all monitoring entities, regional monitoring protocols for sampling and analytical methods have been developed. Through use of these protocols all monitoring information collected within the watershed will be comparable and will be submitted to one central database. Current agency monitoring sites for stream monitoring will be maintained with future evaluations allowing relocation of resources or addition of new sites.

As previously stated, elements of the GBRMP will not attempt to address localized effects of NPS control measures. Information on effects of site specific activities will be available through NPS pilot projects to be conducted within the Galveston Bay watershed. The TNRCC will establish Galveston Bay as a demonstration area for coastal urban NPS pollution abatement. This will make potential sponsors of NPS pilot projects eligible for State funding as demonstration projects. These demonstration projects will include monitoring to establish BMP effectiveness. This monitoring information will be obtained and evaluated by Galveston Bay Program staff.

In cooperation with the H-GAC, the TNRCC has selected the Dickinson Bayou watershed as a pilot study area to assess the impacts of nutrient loadings from storm water runoff to the Dickinson Bayou watershed. Water quality concerns previously identified in the study area include: 1) nutrient enrichment, 2) critically low dissolved oxygen levels, leading to periodic fish kills, and 3) elevated fecal coliform concentrations. The primary objective of the proposed study is to define nutrient loadings to Dickinson Bayou and secondarily, to define sources of nutrients and their effects on the Bayou. Water samples will be collected monthly and during storm events, and analyzed for a variety of nutrients. First year analyses will include temperature, specific conductance, pH, total alkalinity dissolved oxygen, suspended sediment, chlorophyll-a, chlorophyll-b, phytoplankton biomass, and total and dissolved forms of nitrite, nitrate-plus-nitrite, ammonia, ammonia-plus-organic nitrogen, phosphorous, and ortho-phosphorous. These data will be used to quantify nutrient loads and also will be used to relate nutrient loads to selected land uses in the water shed. Nutrient loadings and yields will be available for instantaneous, storm event, seasonal and annualized time frames.

Stormwater sampling, to be conducted under the soon to be issued NPDES stormwater permits, will be an additional source of information for this action plan. Monitoring information anticipated to be available under this program includes: data collected as part of a dry weather screening program, wet weather screening, representative monitoring from storm event discharges, and monitoring for floatables. The dry weather program will be an ongoing effort to detect and identify illicit connections and improper discharges to the Municipal Separate Storm Sewer System (MS4). (See also Chapter 11.0- Point Sources of Pollution) Wet weather screening will be used to identify areas of excessive pollutant discharges. Floatables monitoring will consist of reports of volumes of debris removed from structures designed for removal of floatable materials. Representative monitoring from storm events will be conducted to characterize the quality of storm water discharges from the MS4. Monitoring at these stations will be conducted to characterize the quality of storm water discharges from the MS4. The Joint Task Force has identified 5 sites for representative monitoring. These sites were selected to be representative of specific land use patterns. Quantitative data collected under this program will be used to estimate pollutant loadings and event mean concentrations (EMC) for each parameter sampled. An EMC is the flow weighted average concentration of a water quality constituent over the course of an entire storm event (Newell, 1992).

Because of their limited circulation, intensity of use, and the potential for pollution from boat maintenance activities, marinas will be designated as special monitoring areas. Recent studies have indicated that the non-point water quality impact to marinas is localized within the immediate vacinity of the marina. Because of these circumstances it may be possible to directly measure NPS improvements through site-specific monitoring. Low dissolved oxygen values and elevated concentrations of copper, lead, and arsenic have been associated with marina sites. The Galveston Bay Program will work with citizens monitoring groups to establish sampling sites to monitor DO in marinas as part of this monitoring element.

Non-point sources contribute greatly to suspended solids loads to the bay. The ultimate repository for these suspended solids is bay-area sediments. The sediment quality monitoring element of the GBRMP can therefore serve as an indictor of NPS effects on the bay. NPS are important contributors of several priority pollutants such as PAHs and heavy metals. Sediment quality studies performed by GBNEP found the most significant effects in small enclosed bays near highly urbanized areas. Preliminary data from the EPA, 1993 R-EMAP study which included sediment stations near selected marinas, found elevated levels of tri-butyl tin associated with the marina stations (E. Hornig, U.S. EPA-Region 6, personal communication). Sediment monitoring of these small embayments will continue as a special element within the GBRMP.

Loading estimates indicate that non-point source runoff is probably the largest contributor of fecal coliform to Galveston Bay (GBNEP, 1994). The National Urban Stormwater Runoff Program identified coliform bacteria as the primary indicator of adverse effects of urban runoff to marine waters (USEPA, 1983c). In the Galveston Bay system several streams appear, at times, to exceed the state water quality criteria for fecal coliform bacteria and it is believed that non-point sources of fecal coliforms are significant contributors of coliform bacteria which are responsible for preventing oyster harvesting in some parts of the open bay. As a matter of fact, in several oyster harvest areas, this relationship is so well documented that oyster harvesting is conditionally approved based on meteorological conditions. For example, in conditionally approved area 1, when a 7-day rainfall a San Leon or the closest available National Weather Service rain gauge exceeds 2 inches, this area is closed for harvesting. Historical information shows that coliform counts in these areas increase according to the flows received from nearby streams. Much of this increase is attributed to NPS contributions. GBRMP fecal coliform data may be useful as an indicator of the effectiveness of NPS actions in some areas.

An important component in development of NPS loading estimates is land cover information. An additional monitoring element which will provide valuable information will be the land-use monitoring element of the habitat quality monitoring program. Obtained from the land use classification data available from the TPWD Coastal Habitat Monitoring effort this information will allow updates of land-use information on a two-year cycle. Land-use has been closely linked to NPS pollution loads. Using updated land-use information, estimates of urban NPS loading can be revised.

Chapter 12

Point Sources of Pollution

Priority Problems

The impacts of point source discharges on water and sediment quality in Galveston Bay have been studied for years. Point source discharges come from municipal and industrial facilities, bypasses and overflows from municipal sewage systems, unpermitted and illegal discharges, and produced water from oil and gas operations. Since the 1970s pollutant loads from large municipal and industrial facilities have been closely controlled through state and federal permitting rules. The permitting process has been successful in reducing the concentrations of pollutants entering the system from these sources. As a result this action plan focuses on sewage bypasses and overflows, illegal connections to storm sewers, and oil and gas field operations.

Raw or partially treated sewage continues to enter Galveston Bay from Publicly Owned Treatment Systems (POTWs) due to design and operational problems, especially during rainfall runoff. These charges contribute to eutrophication, bacterial contamination, shellfish harvest closures, and other water quality problems. Illegal storm sewer connections also contribute to this problem. Oil and gas produced water discharges high concentration salts and hydrocarbons which also have deleterious effects on water quality and aquatic life

Management Goals and Objectives

The following high priority management goals are established by *The Plan:*

- Elimination of wet weather sewage bypasses/overflows,
- Elimination of pollution problems from poorly operated small wastewater treatment plants,
- Eliminate illegal connections to storm sewers, and
- Eliminate harm from produced water discharges.

To achieve these goals the following plan objectives and management action plans were adopted:

Objective 1	By 2004, develop sufficient capacity to control a 5-year storm.
Action PS-1	Determine location and extent of bypass/overflow problems.
Action PS-2	Eliminate or reduce bypass and overflow problems.
Objective 2	By 2004 ensure that all POTWs operate in accordance with permit requirements, and consolidate small plants where feasible.
Action PS-3	Regionalize small wastewater treatment operations.
Action PS-4	Improve compliance monitoring/enforcement in small treatment plants.
Objective 3	By 1997, eliminate all identified illicit connections to storm sewers.
Action PS-5	Implement a dry-weather illegal connection program.
Objective 4	Eliminate harm from produced water discharges to Galveston Bay by 1997.
Action PS-6	Issue NPDES Coastal General Permits or eliminate harm from oil field produced water discharge.

Data Information Needs

Monitoring effectiveness for this action plan will consist of primarily programmatic monitoring. The plan requires actions at local levels which will result in reduced pollutant discharges, especially of fecal coliform bacteria, to the Galveston Bay system. It is not within the scope of this monitoring element to evaluate water quality on such a site-specific level that it will provide the specific information required to answer these questions. The GBRMP will address the larger issues of overall loadings to the bay and impacts to the bay from such loadings.

Programmatic Monitoring

Specific tracking responsibilities for The Program are given in *The Plan,* so little will be said about these requirements. Objectives within this action plan are directed toward ceasing certain activities, therefore program success will be measured at the level at which these activities take place. In a broader context of environmental monitoring they are addressed in the water quality element of the monitoring plan (Chapter 10). Each of the actions PS- 1,2 & 5 requires the development of local programs to address the issue of illicit connections, bypasses and overflows. Preliminary success of the plan action will be determined through compliance with requirements. Bay area permit holders will be surveyed for development and adoption of:

- Specific programs to evaluate bypass/overflow problems,
- Corrective action plans to eliminate identified problems, and
- Dry-weather illicit connections to storm sewer systems.

NPDES and state permit holders are required to report any bypass or overflow incidents both to the state and EPA. Reductions in reported incidents and volumes of bypass/overflow per incident will be evaluated by this program as a potential measure of action plan success.

Plan action PS-4 calls for the evaluation of EPA and TNRCC compliance monitoring and enforcement strategies. Two positive outcomes of this evaluation, according to the plan, would be a shift in focus toward smaller systems and increased commitment and funding for these programs. The number of inspections performed and the relative percent dedicated to smaller systems can be monitored as a relative measure of success. Programmatic monitoring for evaluating progress for produced water discharges will include tracking the permit issuance process.

Environmental Monitoring

The greatest impact of this action plan would be in the reduction of untreated sewage entering the bay system. This is traditionally measured in terms of fecal coliform bacteria counts. Both the Regional Monitoring Program and the TDH National Shellfish Sanitation Program will provide information on fecal coliform counts in Bay and tributary waters. This program regularly monitors fecal coliforms often after rain events. As previously stated much of the impact to this resource is attributed to non-point sources. Illegal bypasses and overflows are usually associated with precipitation events as are non-point sources. Trends in fecal counts in areas most impacted by point source discharges would be the first to show improvements. The monitoring steering committee will work with program staff to locate monitoring stations in these high impact areas.

The City of Houston, Department of Public Works and Engineering (DPW&E) conducts a dry-weather discharge monitoring program which will be incorporated into the tributary monitoring element of the regional monitoring program. As part of this program DPW&E monitors 45 stations in the tidal and non-tidal portions of Houston's major bayous. Most sites are sampled weekly. Parameters monitored include DO, temperature, pH, ammonia nitrate, BOD TSS, conductivity and fecal coliform. The Galveston Bay Program office will work with other entities to encourage implementation of such monitoring programs as part of their responsibility to identify and correct illicit sewer connections.

An additional, but largely localized, point source of pollutants to the Bay are produced water discharges. In the process of recovering oil and gas, brine or produced water is withdrawn from underground formations. The Texas Railroad Commission reports that in 93 discharges were permitted in 1991, discharging up to 15.2 million gallons of produced water per day (mgd) to Galveston Bay and its tributaries. By 1993 this number had been reduced to 62 with a daily discharge estimated at 5.8 mgd.

Substantial negative impacts are associated with such discharges especially in low energy and near shore environments. Some observed effects are; oil sheens, contamination of sediments with oil and chlorides, elevation of and chemical alteration of salinity, and toxic lethal and sub-lethal impacts to plant and animal life. Because of the localized effects of such discharges it is unlikely that the Regional Monitoring Program will detect impacts from produced water discharges.

Plan objective 4 (Action PS-6) calls for the elimination of harm from produced water discharges. The monitoring plan does not, at this time, recommend a specific monitoring element directed at this action. If implemented the proposed EPA permits would result in discharges from this source ceasing, and therefore reducing harm. In this case a survey of selected impacted areas would be conducted over a limited lifetime to document recovery. If a treatment process for produced water is developed instead, and there are no monitoring provisions in the permit to assure reduced harm, then a sampling element would be developed. This monitoring element would include benthic surveys, sediment chemistry, and possibly sediment toxicity testing.

Chapter 13

Communicating Results: Data and Information Management

Priority Problem

One of the limitations of estuary monitoring systems across the country, including Galveston Bay, is that results from different monitoring programs are not easy to compile for ecosystem analyses. Agencies maintain different data bases and report formats, acquisition of data can be time-consuming, and no centralized data management system is currently available to report on overall trends. To alleviate these problems, a Data and Information Management System (DIMS) for Galveston Bay has been developed as an integral part of the Regional Monitoring Program.

DIMS Objectives

The Galveston Bay DIMS must operate on several levels. At one level, the program must be concerned with the management of a system which will accommodate the data to be generated throughout the Galveston Bay monitoring effort. On a higher level the program must work to facilitate exchange of a wide variety of data types between state, local governments and organizations, and federal agencies. Critical among these data types will be the development of retrieval and storage systems which will allow the exchange of geospatial information. To address these needs the Galveston Bay DIMS has been structured to perform the following functions:

- Ensure the long-term integrity, storage, and accessibility of data collected by Galveston Bay's Regional Monitoring Program,
- Ensure data quality,
- Improve the access to information at various decision-making levels,
- Facilitate the integration and analysis of existing physical, chemical, and biological data to generate information useful to resource managers,
- Support statistical, graphical, spatial analysis and mapping of monitoring data, (e.g. power analyses, computer-compatible geographic information system format) ,
- Facilitate access to large amounts of monitoring data from disparate data bases located throughout the state,
- Allow multiple levels of user access to raw monitoring data, data quality information, summary statistics, and maps
- Integrate geographic information system (GIS) functions with appropriate databases.

Summary of Agency Data Management Systems

There are 19 programs presently conducting monitoring in Galveston Bay. In most cases the data are stored 1) on in-house computers under a variety of formats, or 2) on paper. Although most data are made available to the public, access is often difficult. There is no central data storage system that would allow easier access for the public or the agencies presently concerned with monitoring Galveston Bay. Some duplication of effort is noted, particularly for point source monitoring. Most efforts are directed at fulfilling specific agency mandates and have not been geared to ecosystem scale assessments. Ward and Armstrong (1992) cite numerous challenges encountered in compiling 26 data sets for such an analysis. McFarlane, (1991a and 1991b) also documents monitoring deficiencies encountered in obtaining and compiling historical data sets.

To address some of these problems during the development of *The Plan*, several GBNEP projects were conducted to compile data sets from diverse sources and to allow easy exchange of existing bay information. For example, the Galveston Bay Information Center was developed to serve as a clearinghouse for all types of literature about the bay. A number of these same data sets were also distributed to the Texas Natural Resource Information Service (TNRIS).

State-wide Data Integration and Exchange Efforts

There are several existing database management systems (DBMS) and Geographic Information Systems (GIS) running on various platforms at the local, state, and federal agency level. The diversity of existing and planned DBMS applications, GIS applications, and hardware platforms at the agency level reveals a determined use of best available technology. However, these conditions have made it difficult for agencies to access, query, transmit, and analyze resource data in an efficient and timely manner. Getting different DBMS on different hardware platforms to communicate is technically challenging. Currently, no statewide computer network system exists to quickly and easily share data among local, state and federal resource agencies.

In 1989 the Texas Legislature enacted legislation which requires that state agencies share information and information resources. In the same year, the Department of Information Resources (DIR) was established to provide the leadership role in this area. The Texas Geographic Information Systems Planning Council was formed to coordinate an interagency effort to improve and expand the development of geographic information systems and to make recommendations to DIR concerning GIS policies to achieve this goal. Members include representatives from over 20 state and local agencies (Table 13-1). A number of committees and sub-committees have been formed to deal with issues such as: development or acquisition of geospatial data; data standards, including output format standards and spatial information standards; improving network data accessibility among member agencies; development of global positioning systems; remote sensing and TIGER updates. For example the Standards Committee has recently proposed standards and Guidelines for Geographic Information Systems in the State of Texas (TGISPC, 1992), which specifies standards related to :

TABLE 13-1. TEXAS GIS PLANNING COUNCIL MEMBERSHIP

Advisory Commission on State Emergency Communications (State 911)
Comptroller of Public Accounts
Department of Information Resources
General Services Commission
Legislative Council of Texas
Lieutenant Governor's Office
Office of Attorney General
Office of Court Administration
Office of the Secretary of State
Public Utility Commission of Texas
Railroad Commission of Texas
Secretary of State
Texas Department of Commerce
Texas Department of Criminal Justice
Texas Department of Human Services
Texas Department Of Transportation
Texas Education Agency
Texas General Land Office
Texas Historical Commission
Texas Health and Human Services Commission
Texas Natural Resource Conservation Commission
Texas Natural Resources information Service
Texas Parks And Wildlife Department
Texas Rehabilitation Commission
Texas Water Development Board

State Universities
The Bureau of Economic Geology, the University of Texas at Austin, Texas Agriculture and Mining University (TAMU)

Ex-officio memberships— Regional and Private Sectors
Texas Mapping Advisory Committee
Texas Association of Regional Councils
The Texas Association of Appraisal Districts

Ex-officio memberships— Federal Sector
US Geological Survey- National Mapping Division

- Cartographic standards,
- Data dictionary,
- Data interchange, and
- Data layer classification.

The GIS Policy Council will continue to work to provide the leadership at the statewide level to assist in the development of GIS technology and data networks for the cost-effective development of geospatial data applications. Currently, statewide efforts are in early states of planning, with no computer network system existing to quickly and easily share data among resource agencies and organizations. Because there is no existing system which would accommodate GBNEP's data information needs, GBNEP has planned a regional DIM system that conforms to existing and planned local, state-wide and agency data information management plans wherever possible.

Current Activities in Data Networking

Several pilot and developmental programs are currently underway in which the Galveston Bay DIM system could participate in the design and implementation of a state-wide data integration and sharing system.

One such pilot program currently under development is the Wetland Resource Database which has been developed as a joint project of the Texas GLO and the Texas Natural Resources Information Service (TNRIS). This project funded by a grant from the USEPA-Region 6 Wetlands Program is a distributed data management model which uses InterNet connections indexed on Mosaic software. This system provides real-time connections to client state and federal agency databases. This one year program is currently completing a peer review process and has a prototype server running on a limited basis. Clients currently participating in this pilot program are GLO, TPWD, TNRCC and DIR on the state level and the USEPA Region 6 office. The NMFS and USFWS are limited users of the system.

If funding is approved for the second phase of this project, efforts will be directed at a more formal implementation of the network: including formalizing current connections; formalizing TNRIS as the hub of the network; and continuing to work on resolving identified problems. Included in the new workplan will be plans to broaden the scope of involvement in the project. Specifically targeted groups include the Galveston Bay and Corpus Christi Bay National Estuary Programs and coastal universities and libraries.

Another effort currently underway is the Gulf of Mexico Information Sharing Network for Ecological Protection. Through this program the GBNEP will be provided computer hardware and software support to link the Gulf NEP's through the InterNet. This will be a network designed to address sharing of information pertaining to ecological protection which will allow Gulf of Mexico NEPs and the Gulf of Mexico Program to share information with citizens, universities and other governmental agencies.

Design of Galveston Bay DIMS

Overall Systems Design

To meet the demands of identified uses, a distributed data management model will be used to develop the DIM system. Such a system will allow integration of Galveston Bay monitoring data and will allow access to available information from various other data systems. As Figure 13-1 illustrates , a distributed data management model assumes that data are maintained in several remote databases, which are linked through a network. Each participating agency maintains regional

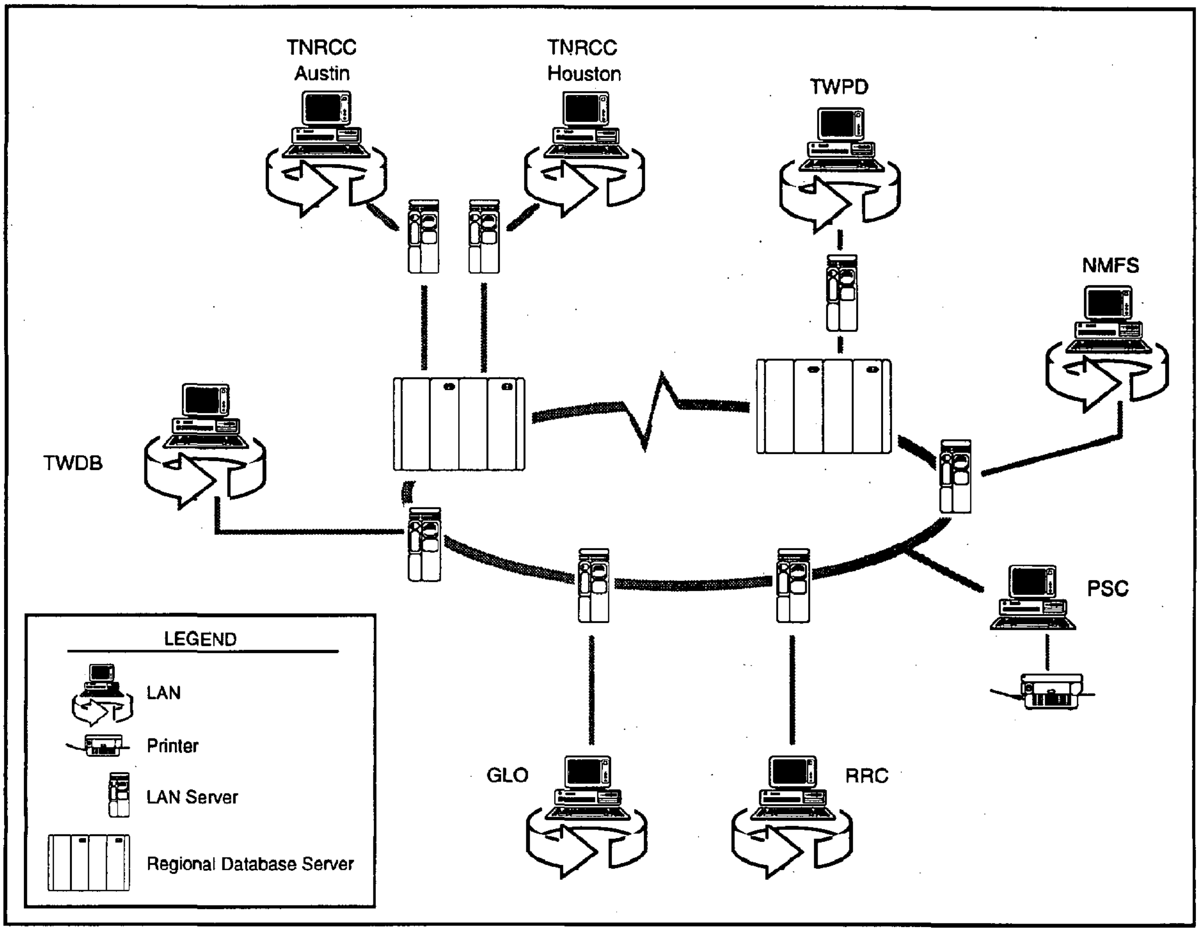


Figure 13-1. Distributed Data Management Model. (For illustrative purposes only, not intended to show all participating organizations.)

monitoring data that it has collected on its own database server. All participating agency database servers are linked over a WAN. A centralized data dictionary lists the location and contents of distributed databases.

Advantages and disadvantages of distributed systems are listed in Table 13-2. Standardization of data and information management protocols and communication among database managers are crucial to this strategy's success since distributed databases tend to diverge —in structure and function — in response to diverse needs of the primary agency.

Local Network Design

The local element of the Galveston Bay DIM system will be implemented in phases. In the first phase, Galveston Bay's DIMS will emphasize adoption of standardized data file structures and implementing data storage and retrieval from a centralized system. Centralizing data in one database server will simplify the tasks of storing, maintaining, locating, querying, and retrieving regional monitoring data. Under

TABLE 13-2. ADVANTAGES AND LIMITATIONS OF DISTRIBUTED DATA MANAGEMENT MODELS

Advantages

- Data are maintained by those who are primarily responsible for their collection and use
- Data are "local" to those who use the data most often— on average, 90% of the time data are used by local users; 10% of the time data are used by other users
- Design facilitates timely data checks by persons who are most familial with the data and associated common data errors
- Design allows local autonomy and facilitates rapid system evolution in response to user needs

Limitations

- Greater potential for multiple versions of the data leading to loss of data integrity and inconsistent analyses
- Extensive transformations of data formats are usually required before data may be analyzed — NEPs have found that up to 40% of the data analysis budget is spent transforming data
- To date, environmental data have not been readily accessible, which has led to long delays in data analyses and reporting
- Costs may be higher due to maintenance of multiple systems and staff, and re-standardization of diverging distributed systems

this DIMS the centralized data base will be housed at the Houston-Galveston Area Council (H-GAC). H-GAC has been named as the regional provider in the state data information system and is responsible for conducting of the Texas Clean Rivers Program (TCRP) in the Galveston Bay area. Through the TCRP, H-GAC is responsible for completing a comprehensive assessment of water quality in the basins surrounding Galveston Bay. One component of the TCRP is to act as a central clearing house for water quality information. In this role, H-GAC will serve as custodian and repository for all Galveston Bay regional monitoring data.

Later phases will include modifying the system to include linking all local participating agency database servers through the distributed type data management system currently being developed by the DIR. In this system all participating agency servers are linked through the InterNet. The H-GAC server will serve as the link from the local network to the statewide WAN. In this system, as in the previously described local network, each participating agency maintains monitoring data that it has collected on its own database server. A central index or data dictionary at H-GAC will list the location of custodial databases of interagency interest The inquiring agency's server will locate and retrieve requested data from the appropriate data base server. Examples of data that may be accessed through this system are core base maps developed by other state/federal agencies, TPWD wetland classification maps, state-wide digital orthophoto quarter-quads, regional land-use maps from the GLO or other agencies, the TNRCC's state Surface Water Quality Assessment Data base, and other environmental data.

Network Architecture

Network media will be required to connect database servers regardless of the data management model selected. Media that link remote agency databases range from telephone lines to satellite networks. Establishing a network requires more than a cable linking two or more servers— choosing the appropriate network architecture also involves considering factors such as distance, amount of data transferred, transmission speed, and cost (Figure 13-2).

The network architecture of the Galveston Bay DIMS is also planned to be implemented in a phased approach. The initial phase will be a direct link between the H-GAC and the Program Office. The link will utilize integrated Services Digital Network (ISDN) technology. The ISDN program digitizes the telephone system and eliminates analog voice lines. This process divides the available bandwidth into three data channels: two move data at 64 Kbps and one moves data at 16 Kbps. A pilot project to evaluate such a connection is currently underway. This pilot involves establishing direct links between the H-GAC, Texas Department of Transportation- District 12 office, and the Metropolitan Transit Authority (Metro). This pilot will serve as a model for the H-GAC - Galveston Bay Program Office link.

Such a direct link would be critical in the Program's development of GIS capabilities. GIS files are usually large and require extended transmission periods to transfer the data and would require large amounts of storage at the program for these coverages if operated on a file transfer basis. Development of GIS capabilities is seen as an important tool, but personnel and budgetary requirements to develop and maintain comprehensive GIS analytical capabilities would be prohibitive at this time. Development of a direct link to H-GAC will enable the Program Office to access the broad range of GIS capabilities and extensive GIS coverages already in place at H-GAC on a "real-time" basis. H-GAC runs Arc/Info® GIS software on UNIX workstations. To take advantage of the H-GAC GIS system the DIMS recommends Arc/Info® ARCVIEW 2 software electronically linked to the main server at H-GAC as the level of entry into GIS. ARCVIEW 2 will allow the integration and manipulation of intermediate and final GIS products needed for this program without the prohibitive costs of operating and maintaining a comprehensive GIS system.

The next phase of the DIMS network architecture to be developed involves providing access to other monitoring agencies in the Galveston Bay area to the Galveston Bay DIM system. This access will be provided initially through dial-up connections using slip technology to increase data transmission rates. If remote data access activity increases dramatically, dedicated or direct lines will be established to link data base servers. This link will use the InterNet to network the servers and their associated data bases.

Another consideration, for this program, is the availability of external sources of information and the network that will best provide that access. Two of the existing network systems previously discussed, the Wetland Resource Database and the Gulf of Mexico Information Sharing Network, utilize the InterNet for data transmission and retrieval. Connectivity to the InterNet and hardware/software to operate on the InterNet will be sponsored by the Gulf of Mexico program. Having InterNet Connectivity will also provide access to the Wetland Resource Database.

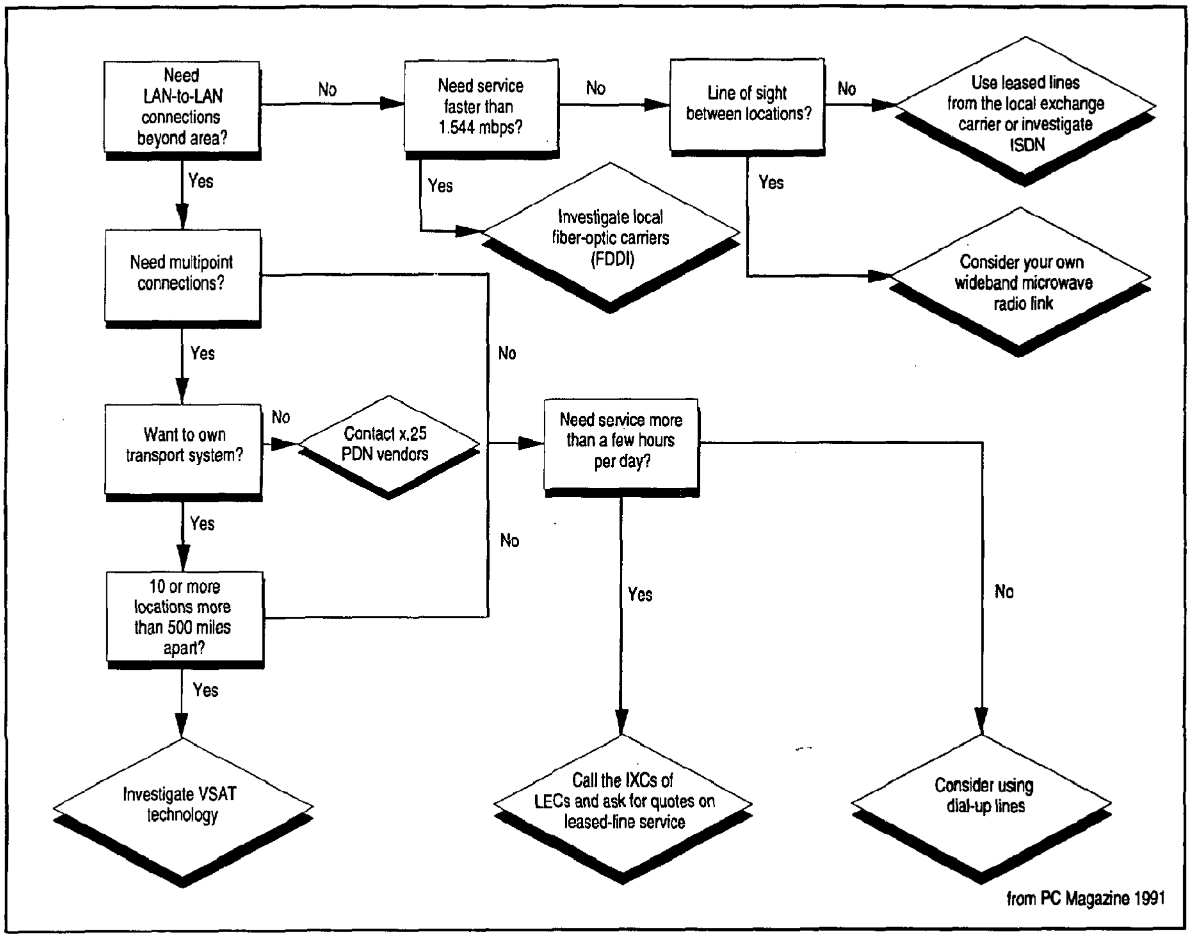


Figure 13-2. Decision chart for selection of network media.

DIMS Systems Administration

Galveston Bay's DIMS Steering Committee will be responsible for overseeing the implementation of the DIMS, including; approving all DIMS system modifications, securing future funding sources, and making data management recommendations to H-GAC and the Galveston Bay Program office. The H-GAC will be responsible for administration of the Regional Monitoring Data system. These responsibilities will include:

- Providing DBMS technical support to agency database managers and system users
- Designing and implementing user interfaces and/or other system applications
- Securing sources of financial support for the system

Additional specific responsibilities will include supervision of system quality assurance and implementation of system upgrades. Future responsibilities will include; implementing and maintaining the WAN and implementing and managing Public Service Centers (PSCs). It is recommended that the H-GAC become a member of the Texas GIS Planning Council, GIS Standards Committee and GIS Managers Committee.

Database Server Managers

In the future phases of DIMS implementation, as other agency servers are linked to the system, agencies will have certain responsibilities. Agencies with primary responsibility for housing regional monitoring data are responsible for updating and adding new data sets to their database server system. Database server managers are responsible for conducting standard data QA/QC checks established as part of the DIM strategy. They are also responsible for ensuring that any upgrades of their DBMS does not disrupt transparent querying and access to regional monitoring data stored on their database server. Furthermore, database server managers are responsible for correcting and updating data sets as specified by the submitter.

It is highly recommended that the H-GAC and all database server managers consistently meet to review system maintenance activities. The systems administrator and servers managers will produce an annual report describing:

- Present status of the system
- Problems encountered and how they were resolved
- Next year's proposed goals and how they will be achieved
- Estimated maintenance and enhancement costs

Data Types

The DIMS system will support the following data types:

- Discrete and continuous numeric monitoring data
- Nonparametric monitoring data (e.g., presence/absence data)
- Text or memo formats
- Maps and charts, i.e., geographically referenced data.

Sufficient information (i.e., metadata) must be associated with the monitoring data to ensure that secondary users can correctly use and interpret the data. These metadata include:

- Quality assurance/Quality control data (e.g., blanks, spike recoveries),
- Measurement units (e.g., mg/kg, ug/l)— not ppm or ppb which are ambiguous,
- Detection levels for chemical data (e.g. minimum analytical levels), and
- Data qualifiers such as "non-detected" and "not analyzed".

The use of QA abstracts will be implemented which will be directly linked to the monitoring data. Each data QA abstract will summarize information that secondary users need to know when deciding the value of a particular data set, such as contact person, date of survey, list of stations, sampling methods, analytical methods, summaries of QA/QC data, and a brief description of important or anomalous conditions pertinent to the collection of the data.

Core Base Maps— Galveston Bay's DIMS system will store core base maps in a central location in accordance with the state GIS Planning Council's recommendation. Participating agencies may request copies of specific core base maps and have them mailed on magnetic disks or optical CDs if electronic transmission is not possible. Core GIS data sets will be kept and maintained on H-GAC servers.

Standard File Structures and Formats

Currently, participating agencies store the same type of data in dissimilar file structures making it difficult to transparently query and retrieve data. The Galveston Bay DIMS will overcome this difficulty through the use of standard file structures and a standard database access interface.

A standard file structure will be established for each data type (e.g., water quality data, population abundance data, toxicity testing data). The Galveston Bay monitoring Work Group working together with all participating agencies will develop or adopt a standard file structure for each data type. Examples of information to be developed are:

- Numbers and names of data fields
- Appropriate field formats (e.g., numerical, alphanumeric),
- Key fields that link relational databases
- Data codes

Database Queries / Transfer

Data Queries— Currently, different agencies use different Data Base Management Systems (DBMS) running on different platforms making it difficult to seamlessly query the database. Initially, the centralized data base will utilize a standard documented database access vehicle such as Standard Query Language (SQL) for data queries. In later phases, the distributed databases will all use the same access vehicle.

Data Transfer— The system administrator will work with the data managers at each participating agency to adopt the standard DBMS or develop translation programs which will 1) translate from agency file structures to Galveston Bay's standard file structure for data storage and 2) provide translation from Galveston Bay's standard structure to agency file structures for retrieval (Figure 13-3). This will allow agencies to manipulate, analyze and display all data residing in the central database initially and distributed databases ultimately using familiar software applications available through their agency.

Data Transfer Formats— The database must have the capability to download data easily to other data analysis and presentation programs. The Texas GIS Standards Committee recently recommended that Spatial Data Transfer Standard (SDTS) format be used to facilitate the exchange of GIS information (TGISPC, 1992). SDTS format will be adopted in accordance with this committee's recommendation. Other GIS standards developed by the GIS Standards Committee will be incorporated into Galveston Bay's DIM strategy as appropriate.

Currently, there are no standard data transfer formats for parametric data. The GIS Standards Committee has recommended that flatfile, non-compressed ASCII format data interchange be employed for the transfer of parametric data.

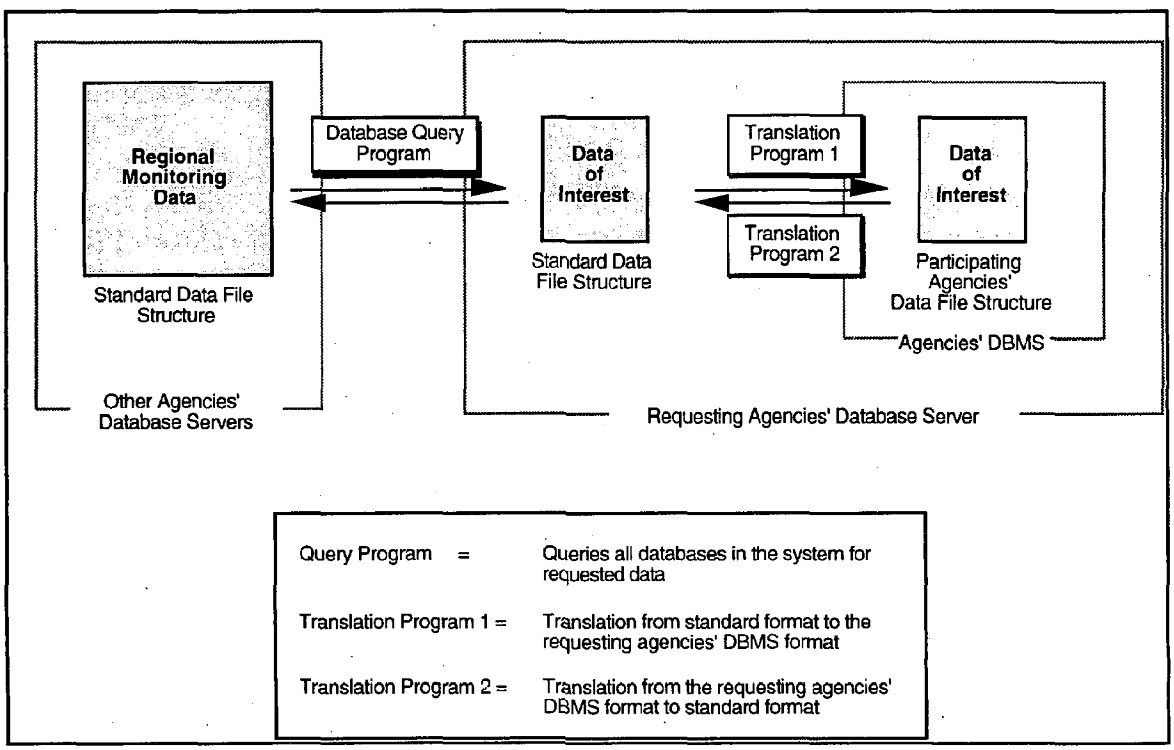


Figure 13-3. Three types of data processing programs.

Data Quality Assurance / Quality Control (QA/QC)

Data Accessibility— Maintaining the integrity of data stored in the system is critical to ensuring user confidence in the system. Data stored in the DIM system can be queried, read, copied, and downloaded to workstations for local manipulation and analyses. Initially this will be available only through requests to H-GAC or the Program Office. As direct access to the system is expanded users of the system will have read only access. Additions and updates to the data will only be made through standard quality control protocols established at the outset of the system's implementation.

Data Submission— Standardized procedures for checking submitted data will include: computerized code and range checking, technical data review, and preparation of a data QA abstract. The data abstract is for describing sampling and analytical methods, QA/QC information, and any other pertinent metadata information needed to assess data quality. Data submitters are responsible for compiling regional monitoring data, conducting data QA/QC checks, and submitting both their data and data QA abstract to the H-GAC for entry into the Galveston Bay database.

Computerized code and data range checks will be performed on the data prior to its entry into the central database. Any errors or discrepancies will be resolved before data is loaded onto the system. Users will not be permitted to make *ad hoc* modifications to data stored in the system. Additions and updates to the data will only be made through standard quality control protocols established at the outset of the system's implementation.

Communicating Monitoring Results

The system will support the following user groups:

- Galveston Bay Council,
- Technical and scientific staff of participating agencies,
- Technical and scientific staff of non-participating agencies,
- Private industry,
- Public interest groups,
- Schools, and the
- General public

Technical staff of non-participating agencies, private industry, public interest groups, schools, and the public will have access to raw monitoring data. In addition there will exist the ability to retrieve selected summary statistics and display these data on core base maps. Requests for data will be handled through H-GAC or the Program Office. In the future the Program Office will support evaluation programs for development of direct link public service centers (PCSs) at strategic locations. These will be established to support direct access to the system for non-participating agencies, private industry, public interest groups, schools, and the general public. Selected bay-wide summary statistics will be available to the public for downloading at the service centers. Requests for raw regional monitoring data will continue to be made through the H-GAC or the Galveston Bay Program Office.

Information from The Galveston Bay Regional Monitoring Program will be available in two formats: technical reports for the scientific community and non-technical briefs for the lay public. Programs will be written to automatically conduct the appropriate data queries, data retrievals, data analyses, and data presentations (e.g., graphs, maps). Ad hoc analyses may be used, as needed, to supplement these fundamental data analyses. A set of most requested bay information may be published in an annual report as well as made available on-line in the system.

The primary purpose of the DIMS is to provide data which can assist in establishing the link between management goals and objectives and environmental results. The Galveston Bay Program Office will be responsible for evaluating and analyzing the results from the monitoring program as they relate to Plan goals and objectives. Evaluation of monitoring program results will provide information for feedback to the program on two levels. Such evaluations of the data will establish whether the monitoring program is providing the expected information for assessing plan actions and if changes to the program are needed to obtain the necessary information. Secondly, evaluations will determine if data supports a conclusion as to whether resource management goals are being met.

This information will be disseminated to provide information to resource managers, scientific and technical sources, and the general public. Publications such as the Galveston Bay *Bay Line*, a quarterly newsletter published by the Galveston Bay Program, will inform the public on Bay issues and generate public interest and support for program initiatives. This information will also be made available to the scientific community in technical publications and through papers and poster presentations at scientific and technical meetings.

To supplement publications and to allow additional data presentation the Galveston Bay Program will continue to host the biennial Galveston Bay Symposium. The goals of this symposium are to: identify Bay projects being conducted by institutions other than the Program,; to promote peer interactions among scientists involved in this research; to improve our understanding of estuarine problems; and to encourage project coordination in an ecosystem context. (GBNEP, 1993)

<u>Bay Barometer</u>

A potential tool for communicating the status of the health of the ecosystem is the development of a Galveston Bay barometer similar in approach to the one used in the Chesapeake Bay Program. For example, such a barometer could include several easily measured components of the Galveston Bay system. This information would be published as a regular feature in the Galveston Bay *Bay Line*. The Bay Barometer concept will be developed by the Galveston Bay Program Office.

Sources of Financial Support

Several candidate sources of financial support for the implementation and maintenance of the DIMS system have been identified, including

- Corporate sponsors,
- Other state-wide or gulf-wide data sharing projects, and
- Line-item support from the State.

Private sector corporations and software/hardware vendors will be sought out to sponsor, in part, the cost of hardware and software needed to implement the DIMS system. Candidate corporate and vendor sponsors will be aggressively pursued by the chair of the Steering Committee, H-GAC, and the Galveston Bay Program Office.

Furthermore, the implementation of Galveston Bay's DIMS system may be partially supported through other state-wide or gulf-wide data management projects including the Coastal GIS Initiative, the Natural Resources Inventory, the Texas Clean Rivers Program, and the Gulf of Mexico Program. The DIMS Steering Committee, H-GAC, and the Galveston Bay Program Office will pursue all state-wide and gulf coast financial sources. They will aggressively approach the legislature to seek line-item status for Galveston Bay's DIMS system.

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Appendix A

Galveston Bay Regional Monitoring Protocols

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INTRODUCTION

1.1 BACKGROUND

The Clean Water Act as amended by the Water Quality Act of 1987 established the National Estuary Program (NEP) to promote long term planning and management in nationally significant estuaries threatened by pollution, development, or overuse. Section 320 of the Clean Water Act describes the establishment of a management conference in each estuary to develop a Comprehensive Conservation and Management Plan (CCMP). It also establishes requirements to monitor the effectiveness of actions taken pursuant to the plan.

The Galveston Bay National Estuary Program (GBNEP) was established under the authority of the Water Quality Act of 1987 to develop a CCMP for Galveston Bay. In 1990, work commenced to:

- Identify specific problems facing the Bay
- Compile bay-wide data and information to describe the status, trends, and probable causes related to the identified problems
- Create the CCMP document to enhance governance of the Bay at the ecosystem level.

GBNEP is accomplishing this work through a cooperative agreement between the U.S. Environmental Protection Agency (USEPA) Region 6 and the State of Texas (administered by the Texas Natural Resources Conservation Commission [TRNCC]). The structure of GBNEP reflects a strong commitment to consensus building among all Galveston Bay user groups, government agencies, and the public. This regional effort reflects thousands of hours of involvement by individuals who use, enjoy, or help manage this vital coastal resource.

GBNEP held a Regional Monitoring Conference in July 1992 to examine the need and feasibility of a regional monitoring program for the estuary (Tetra Tech, 1992). The participants included policy makers, resource managers, scientists, and representatives of public and commercial interest groups. From these discussions, a consensus was reached on the following points:

- A regional monitoring program is needed to improve our ability to effectively manage resources in the estuary

- Establishment and management of a technically sound regional monitoring program are feasible

- The details of the monitoring program should be designed by technical experts working with managers and decision makers.

Several monitoring programs are ongoing in the estuary. These programs are being conducted by federal, state, and local government agencies at an annual cost of nearly $8 million. Many of these monitoring programs use different field sampling and analytical methods, and collect data at different sampling locations and on different time scales. Furthermore, monitoring data are maintained at a number of locations, using different database management systems, and are stored in different formats. As a result of the diverse origins and purposes of these programs:

- Uncoordinated data collection efforts are executed

- Data from several monitoring efforts cannot be integrated (i.e., pooled) because
  - sampling or analytical methods are incompatible or
  - sampling locations or times are incongruous

- Data analyses are severely delayed because data are not readily accessible or require significant time and cost to translate into a usable format.

Participants of the Regional Monitoring Conference agreed that a coordinated regional monitoring program would increase the efficiency of monitoring efforts and enhance the usefulness of monitoring data for all persons responsible for managing the bay's resources.

1.2 APPROACH

This is the second of two documents prepared to address the requirement of the CCMP to develop a regional monitoring program for Galveston Bay. The first document (Tetra Tech, 1992) presented the plan or strategy for developing Galveston Bay's regional monitoring program. The development of this plan was based on the approach described in two recent documents: *Monitoring Guidance for the National Estuary Program* (USEPA, 1992) and *Managing Troubled Waters: The Role of Marine Environmental Monitoring* (NRC, 1990).

The first key step was defining resource management goals. Resource management goals describe the desired result of CCMP management actions and provide a point of reference from which managers can assess whether conditions in Galveston Bay are improving, declining, or remaining the same.

The next step is to specify the information needed to assess whether progress is being made toward achieving resource management goals. This information will be used to:

- Determine the status and trends in the condition of bay resources
- Assess the effectiveness of implemented CCMP management actions.

Monitoring objectives define what data and information the regional monitoring program will provide. A key contribution of the Regional Monitoring Plan was the specification of monitoring objectives to guide the design of Galveston Bay's regional monitoring program.

During April 1993, a series of technical workshops was held specifically to develop monitoring objectives for each of the five primary management topics (Water and sediment quality, Species population protection, Habitat protection, Freshwater inflow, and Public health protection). The purpose was to build upon the work described in GBNEP's characterization reports and to define monitoring objectives and corresponding monitoring variables.

Each of the five Primary Topics Task Forces met to discuss and reach a consensus on:

- Priority resource management goals

- Information needed to assess whether progress is being made toward achieving these goals

- Regional monitoring objectives

- Monitoring parameters.

Between June and August 1994, members of the Regional Monitoring Steering Committee convened several times in five Focus Groups (corresponding to Water Quality, Sediment Quality, Habitat Quality, Species Protection, and Public Health). Their aim was, in part, to further define monitoring parameters and recommend which of the existing monitoring protocols were most appropriate for inclusion in the Galveston Bay Regional Monitoring Program (GBRMP).

These parameters and protocols were chosen from the range of existing methods and parameters presently being used by the various agencies in their monitoring efforts within Galveston Bay estuary. The recommended protocols have been judged as best suited to support the Resource Management Objectives developed at the Regional Monitoring Conference.

The existing monitoring activities in Galveston Bay are discussed in detail in the *Galveston Bay Regional Monitoring Strategy* (Tetra Tech, 1994). A summary of these regional monitoring activities of each agency, showing: the number of sampling stations, their data collection activities, the parameters monitored, the analytical methods and detection limit, and the quality assurance/quality control (QA/QC) procedures was developed and circulated among the agency staff comprising the Monitoring Steering Committee (Table 1-1). This table represents the identified monitoring activities presently being undertaken in Galveston Bay. This summary of monitoring activities is the basis from which the recommended monitoring protocols, described later in this document, were selected by the Committee members.

Selection criteria (Table 1-2) were developed as a framework for comparison of existing methods. The selection criteria were also used to evaluate alternate methods. These are methods not presently being used, but have potential to:

- provide ancillary information for minimum extra cost or effort, or

- improve sample collection or analysis by decreasing the present levels of effort (e.g., using *in situ*, automatic measuring and recording probes with multi-parameter sensors).

These criteria will form the basis for an evaluation of the monitoring methods presently employed in Galveston Bay. This approach of incorporating existing monitoring elements has several inherent advantages. The criteria will be most useful in cases where different methods have been used by agencies to monitor the same or similar parameters (e.g., dissolved oxygen, total organic carbon).

Maintaining the comparability of data by recommending an existing method (or in some cases more than one method) will maximize the amount of previously collected data that can be incorporated into the regional monitoring effort. This historical data would not necessarily be as useful if new and different collection methods or analytical methods are followed.

Giving a high priority to the cost of collecting and analyzing data is pragmatic in this era of limited funding and overburdened budgets. This approach will maximize the amount of data that can be collected for a given monitoring budget. Cost efficiency is high when using

Table 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY

Summary of data collection activities, monitoring parameters, analytical methods, and quality assurance/quality control methods by the various agencies/organizations monitoring in Galveston Bay Estuary.

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Texas Natural Resource Conservation Commission (TNRCC)	68 stations	Sediment:	All stations - Routine	EPA Methods (1,2)		TNRCC requires that a minimum of one water quality monitoring program and one water quality sampling program undergo a quality assurance review each fiscal year.
		Chemistry - Ekman dredge	Water:			
	243 sampling activities/year		Temperature, conductivity, pH dissolved oxygen (DO), salinity			
(Kirkpatrick, 1994)		Benthic macroinvertebrates: Peterson or Ekman dredge				
(TNRCC, 1993)			Conventional pollutants:			Projects:
(TWC, 1991)		Nekton:	Biochemical oxygen demand (BOD)	405.1	1 mg/l	- water quality monitoring field data notebook
(Twidwell, 1993 and 1994)		Collection techniques	Total suspended solids (TSS)	160.2	10 mg/l	- standard instrument calibration and notebook
(U.S EPA, 1983 and 1986)		- Hook and line, trotline	Oil and grease	413.1	5 mg/l	- flow measurement records
		- Throwline, handline	Fecal coliform (FC)			- fecal coliform bacteria analysis records
		- 20' minnow seine with 1/4" mesh				- biological sample analysis records
		- Gill nets	Nutrients:			- proper data and sample collection procedures
		- Fish traps	Orthophosphorus	365.2	0.01 mg/l	- quality assurance review follow-up
		- Trawl	Nitrite - N	354.1	0.01 mg/l	
		- Cast nets	Nitrate - N	352.1	0.01 mg/l	Laboratory analysis will meet or exceed the requirements set forth in the TWC Quality Assurance program (3)
		- Water intake screens	Ammonia - N	350.1	0.02 mg/l	
			Total phosphorus	365.1	0.01 mg/l	
		Tissue - 4 preferred species	Chlorophyll a			
		- Hardhead (sea) catfish	Pheophylin a			Data storage:
		- Pinfish				- side by side data comparisons
		- Atlantic croaker	Total organic carbon (TOC)	415.1	1 mg/l	- computerized parameter value editing
		- Redfish (red drum)	Alkalinity	310.1	1 mg/l	
			Chloride	325.3	1 mg/l	
		Plankton:	Sulfate	375.4		
		- Kemmerer sampler	Total dissolved solids (TDS)	160.1	10 mg/l	
		- Van Dorn sampler	Volatile suspended solids (VSS)	624	10 mg/l	
		- Net hauls				
			Select stations:			
			Water and Sediment:			
			Organics - pesticides	608/8080	variable	
			Inorganics - alkalinity, hardness major ions			
			Metals	ICP - 6010	variable	
			Toxicity			
			Organisms:			
			nekton - tissue			
			plankton			
			benthos			
Texas Water Development Board (TWDB)	5 Stations	Semi-permanent moored stations using Data Sonde instrumentation	Water: Temperature, salinity, pH conductivity, DO			Instruments are checked and maintained on a regular basis.
(Brock, 1993 and 1994)	supports TCOON					
	8 Stations	Tide monitoring stations within Galveston Bay	Tidal elevation Some meteorological data			NOAA / NOS QA procedures Data inspected daily

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Texas Parks and Wildlife Department (TPWD) 1. Resource Monitoring *(Bowling and Benefield, 1993)* (Robinson, 1994) (TPWD, 1993a)	149 Stations *Bay and Offshore* Randomly selected from TPWD's grid system The number of usable grids varies for each gear type	Bay Bag Seines: 20 per month Targets juvenile finfish and shellfish *321 usable grids* Bay Trawls: 20 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls 369 usable grids GIW (Gulf Intercoastal Waterway) Trawls: 6 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls 77 usable grids Gulf Trawls: 16 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls Oyster Dredges: 30 per month Targets oysters: market, small, and spat 30-second dredge - 126 usable grids Beach Seines: May - November - 6 per month Targets adults in surf zone of front beach Beach Bag Seines: May - November - 6 per month Targets juvenile finfish and shell fish in surf zone Gill nets: 45 nets set during a 10-week period in the spring and fall Targets adult finfish in bay 4 segments of 150' each, 4 mesh sizes - 3" - 6" 1 per segment, shoreline to Gulf 252 usable grids Hook and line: As required by special study	Water: Temperature, salinity, pH *turbidity, DO* Weather conditions Wind direction Air temperature Organisms: Species Number Weight (select individuals) Length (subsample of 19 ind.) Sex and maturity Large, live fish tagged for growth and mortality			Guidelines follow TPWD Marine Resource Monitoring Operations Manual (4) Gill nets must be set within 1/2 hour of sunset and picked up no earlier than 1/2 hour before sunrise. Work on the last net must start before 11:00 a.m. Field data sheets are edited prior to submission for computer keying Computer printouts of field data are contrasted with field data sheets after computer keying
2. Coastal Resource Harvest Commercial Landings Program *(McEachron, Campell, and* Robinson, 1993) (Robinson, 1994) (TPWD, 1989)	130 - 140 seafood dealers Vessel captains	Seafood dealer submits reports - pertaining to commercial finfish, shrimp, crabs, oyster, and other marine life Length checks of target species - (200 per species) 5 target species - black drum, flounder, mackerel, red snapper, sheepshead Commercial bay/bait intercept program was implemented in May 1994 On-site interviews of vessel captains	Organism: Quantity by weight Number of species Price per pound Trip length Number of drags Total fishing time Minor bay fished Net size Mesh size Amount of live and dead shrimp landed Size of shrimp Species of catch			Guidelines follow TPWD Commercial Harvest Field Operations Manual (5)

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
3. Coastal Resource Harvest Recreational Landings Program (Robinson, Green, and McEachron, 1993) (Robinson, 1994) (TPWD, 1993b)	121 Sample sites 40 additional sites for detecting any change in status Sampling stratified and based on relative fishing pressure at each site. Determined by a computer generated relative pressure system.	On-site trip-end Interviews	Boat registration number Trip length Number of people / residency Minor bay fished Gear: Bait - type and amount Fish landed: Species Total lengths (6 per species) Grade Species sought By-catch - released Trip satisfaction			Interviewers are periodically observed to monitor compliance with operating procedures Guidelines follow TPWD Marine Sport Harvest Operations Manual (6)
City of Houston/Department of Public Utilities (CoH DPU) (Glanton, 1993)	45 Stations in the tidal portions of major bayous		Water: probe Temperature, pH, conductivity Chloride Ammonia - N Nitrate - N BOD TSS FC			
City of Houston/Health and Human Services Department (HHSD) (APHA, 1992) (Fisher, 1993 and 1994) (Krentz, 1993) (U.S. EPA, 1983)	Field Operations : - 54 stream stations - all permitted wastewater dischargers	CoH - HHSD - The Bureau of Public Health Engineering has two groups conducting monitoring				Participate in APG proficiency studies twice each year for each analyte listed (chemistry)
		Field Operations Unit - Stations are all above tidal waters	Water: probe Temperature, DO			Field Notes, information reviewed after computer entry
			BOD	EPA Methods (1) 405.1	4 mg/l	Duplicate
			Ammonia-N	350.1	0.05 mg/l	Duplicate, spike, external QC
			Sulfate	300	2 mg/l	Duplicate, spike, external QC
			TDS	160.1	20 mg/l	Duplicate
			TSS	160.2	4 mg/l	Duplicate
			Oil and grease	413.1	1 mg/l	External QC
			Chloride	300	2 mg/l	Duplicate, spike, external QC
			Trace metals:			
			As	206.2	2 mg/l	Duplicate, spike, external QC
			Cd, Cr, Du, Mn, Zn	200.7	10 mg/l	Duplicate, spike, external QC
			Ni	200.7	25 mg/l	Duplicate, spike, external QC
			Se	200.7	1 mg/l	Duplicate, spike, external QC
			Hg	245.2	0.5 mg/l	Duplicate, spike, external QC
			Pb	200.7 / 239.2	40 mg/l	Duplicate, spike, external QC
			FC	Standard Methods (7) 9221 E(1.)	2 / 100 ML	FC bacterial analysis records
	Quality Assurance Group : - Lake Houston and watershed - 6 major Houston bayous	Quality Assurance Group - These bayou stations are all at USGS monitoring stations and include the lowest USGS station at each bayou	Water: probe Temperature, DO			Field notes, information reviewed after computer entry
			pH	EPA Methods (1) 150.1		Buffer check
			TDS	160.1	20 mg/l	Duplicate
			Sulfate	300	2 mg/l	Duplicate, spike, external QC
			Chloride	300	2 mg/l	Duplicate, spike, external QC
			FC	Standard Methods (7) 9221 E(1.)	2 / 100 ML	FC bacterial analysis records

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Harris County Pollution Control Department (HCPCD) (APHA, 1992) (Barrett, 1993 and 1994) (Tyer, 1994)	9 Stations - Houston Ship Channel 6 Stations - on the *San Jacinto River* Each industrial discharger Municipal dischargers		Water: probe Temperature, DO, flow	Standard Methods (7) DO = 4500-0 G		Calibrate meter prior to each use
			pH	4500-H+		2 buffer standardization and read 3rd buffer prior to each analytical run; restandardize/ *reanalyze violations*
			TOC	5310B	1 mg/l	Standardize prior to each analytical run (optional: check calibration with independent standard), check calibration about every 10 samples and at end of run. Reanalyze violations, including spike analysis
			Trace metals: As Cd Cr, Ni Cu, Mn Zn	 3111/3113 3111 3111 3111 3111	 0.001 mg/l 0.002 mg/l 0.02 mg/l 0.01 mg/l 0.005 mg/l	Two point calibration prior to each analytical run; check calibration about every 10 samples. One replicate analyzed with each run. Reanalyze violations, including spike analysis.
			Total solids (residue)	2540B		Control dish (no sample)
			TSS	2540D		One random replicate with each analytical run and/or replicates on any suspected violations; reanalyze any violation without previous replicate; water blank and control crucible (no sample) with each run
			Ammonia - N	4500	0.03 mg/l	Standardize prior to each analytical run; one random replicate analyzed with each run; check calibration with two different standards (concentrations) one during run and other at end of run
			FC/Fecal Streptococcus (FS)	Modified 9222D/9230C	10 / 100 ML	Periodically analyze replicates, system blank, air density plate and known active sewage
			Volatile acids (VA)	Qualitative		Periodically analyze known cyanide solutions
			Sulfide	Qualitative		Periodically analyze known sulfide solutions
			Chloride	Harris County Method	7 mg/l	Periodically analyze chloride standard
Galveston County Health District Pollution Control Division (GCHD) (APHA, 1989) (Fogerty, 1993 and 1994) (Wright, 1994)	120 Stations including Galveston Island - beach, bayside, ship channel, and bayous Mainland county bayous, creeks, some drainage ditches Texas City Ship Channel and Dike	*Collect water quality samples only* Grab samples usually, composites rarely Samples collected on monthly, bi-monthly, and tri-annual basis	*Date and time* Wind direction Wind speed Cloud cover Rainfall Days prior rainfall and amount Tide (high/low) Flow direction (in/out) Sample depth Air temperature Water temperature	Use NOAA weather information for: wind direction, speed, and rainfall Use daily rainfall data from wastewater treatment plants throughout county		*Field meters are calibrated using* manufacturers guidelines before each use. Manufacturer services meters as necessary. Laboratory uses standard QC methods (blanks, spikes, controls, and duplicates) EPA required controls implemented for those tests performed for contracted services for cities

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
	Permitted dischargers		DO, salinity, conductivity	YSI field meters		
			pH	Corning or Orion meters 4500-H Standard methods		
	Complaint sampling		Water color Observed turbidity or Secchi disc			
				Standard Methods (8)		
			BOD	5210 B	2 mg/l	
			TSS	2540-D		
			FC			
			Occasionally:			
			Chemical oxygen demand (COD)	5220 B		
			Ammonia-N	4500 NH3 B	0.01 mg/l	
			Total phosphorus	4500-P-B-5	0.02 mg/l	
			Oil and grease	5520 B		
			Extra capabilities:			
			TDS	2540-C		
			Volatile suspended solids (VSS)	2540-E		
			orthophosphate	4500-P-B	0.01 mg/l	
Chambers County Environmental Health Department	Trinity Bay - respond to septic/ sewage complaints	No monitoring programs in Galveston Bay				
(Jackson, 1994)	Lake Anuhuac		FC			
U.S. Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program (EMAP) (Heitmuller and Valente, 1991) (Hornig, 1993) (Summers et al., 1992) (U.S. EPA, 1983 and 1991)	5 Stations in the vicinity of 5 marinas 6 Stations in East Bay Bayou	Water quality - two models of dataloggers - Surveyor II - instantaneous measurements - Data Sonde 3 - continuous measurements Water clarity - LICOR L1-1000 containing a submersible light sensor Light penetration - Secchi disk Fish: Trawling with a 16', high rise otter trawl with a 2.5 cm mesh cod end - towed for 10 minutes against tide Target species for tissue contaminants: - shrimp (brown and white) - Atlantic croaker - catfish (hardhead, gafftopsail, and blue) Composite of 4 - 10 individuals per site Bivalves: Modified oyster dredge with collection bag towed over the bottom - 5 minutes at approximately 1 m/s	Water: probe Temperature, salinity, pH, DO Water clarity Water depth Light Marine debris Fish: Number of species Total abundance Gross pathology Bivalves: Total abundance Species composition Shell length Fish and bivalve tissue: Pesticides, PCBs Heavy metals Benthic community parameters Grain-size analyses			Crew training and sample collection: - chief training - crew training - field certification / auditing - testing and scoring of personnel Water quality measurements: Field quality control checks - instantaneous and continuous measurements - All datalogging units are calibrated with documentation within the 24-hour period preceding their scheduled use - side by side measurements between Data sonde and Surveyer (standard) - QC data compiled and evaluated to determine the frequency of acceptable and unacceptable adherence to QA guidelines Laboratory certification and chemical analyses: - laboratories must pass a certification prior to analyzing any samples - usual QC methods (blanks, spikes, controls, and duplicates) - standard reference materials (SRMs) with certified values for metals and organics

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
		Benthos: Young - modified Van Veen grab which samples a surface area of 440 square cm - 3 grabs at base, index, or supplement sites - 5 grabs at indicator sites Grain-size analyses: Small core (60 cc) from each grab - sieved	Sediment: Toxicity Ampelisca abdita Mysidopsis bahia Alkanes and isoprenoids PAHs Pesticides, PCBs Heavy Metals: Ag, Al, Cr, Cu, Fe, Mn, Ni, Pb, An As, Cd, Sb, Se, Sn Hg Butyltins TOC	 10-day acute bioassay 4-day acute bioassay GC/MS GC/ECD ICP-AES ICP-AES GFAA CVAA		Laboratory testing and analyses: - scheduled recounts and resorts for benthic assessments - experimental controls for sediment toxicity testing - scheduled replication for sediment characterization - use of blank, spikes, and standards for chemical assessments - EMAP-E personnel visit each of the laboratories at least once while EMAP-E analyses is occurring
R-EMAP-TX program	33 Stations - 29 systematic grid sites - 4 randomly selected bay sites		Sediment: Detailed chemistry Benthic communities			
U.S. Geological Survey (USGS) (Fisher, 1994) (Liscom, 1993)	2 stage gages 4 automatic monitoring stations 12 stations	USGS - stage gage - Moses Lake - stage gage - Hwy 90 at San Jacinto River Freshwater inflow monitoring	stage and precipitation stage Water: probe Temperature, salinity, pH conductivity Surface water elevation Surface water elevation - hourly *Freshwater inflow - hourly* 4 to 6 samples per year BOD COD FC FS TOC Nutrients Selected pesticides/herbicides Specific conductance Water temperature			Instruments are checked, maintained, and calibrated on a regular basis
Galveston Bay Foundation (GBF)	Approximately 34 stations in tidal segments	Grab samples are taken 1 foot below surface Samples are collected weekly or bi-monthly	Water: temperature, DO, pH, salinity, conductivity, turbidity Weather: wind direction, intensity, days since last rainfall air temp. Other: total depth, water level, odor, site observations, tide, color	Standard Methods: 2550-B 4500-o C 4500-HB 2510 B		GBF follows the Texas Watch QAPjP Monitors receive Texas Watch (TNRCC) training Monitors participate in 2 QC sessions per year Conductivity pens are calibrated prior to each monitoring event DO chemicals are changed every 6 months

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
U.S. Fish and Wildlife Service (USFWS)	Entire estuary - every 10 years	USFWS - National Wetlands Inventory - program of mapping wetlands using aerial photography	Vegetation groups:	Photo analysis Ground truthing		
(Special Study) Galveston Bay National Estuary Program (GBNEP) (Carr, 1993) (Jensen et al., 1993)	24 Stations 16 stations selected in depositional zones away from known point source discharges 8 stations selected based on specific areas of concern A GPS navigation receiver was used determine station locations	Sediment: - collected with a 4" diameter coring device Benthos: - collected with a 2" diameter coring device	Water: probe Temperature, salinity Water depth Sediment: Trace metals: Al, Br, Ba, Cr, Cu, Fe, Mg, Mn, Ni, Tr, Vd, Zn As, Cd, Pb, Se Hg PAHs Pesticides, PCBs TOC AVS Toxicity: *Grandidierella japonica* Pore water: DO, pH, hydrogen sulfide Temperature, ammonia Toxicity: gametes Arbacia punctulata Benthic community parameters Total abundance Species composition Species diversity Species richness	DCP DCP GFAA CVAA MS in the SIM mode CGC Coulometer TOC analyzer GFAA 10-day solid-phase bioassay Fertilization test Morphological development assay		NS&T QA/QC Procedures
National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program (NSTP) (Presley and O'Conner, 1993)		(continued on following page)				NS&T Program Methodology - performance based Analysis of reference materials and control materials is required

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
1. National Benthic Surveillance Project (NBSP) (NOAA, 1993)	9 Stations: a nominal site center has been defined for NBSP sites as an area 2 km in diameter and is revisited for sample collection	Sediments were collected concurrently with fish specimens at each NBSP site Sediment: - specially constructed box corer - standard Smith-MacIntyre bottom grab the water was drained before sediment was taken Fish: - primarily collected by otter trawls towed by NOAA vessels - occasionally by hook and line or gill nets	Sediments: Organic compounds: Pesticides, PCBs PAHs Coprostanol	 GC/ECD GC/FID/MS GC/FID	 0.0001 ug/g 0.0010 ug/g	Trace organic analytical procedures - internal standards are added at the start and carried through analyses Calibration checks - plus or minus 10% of the accuracy based value for standards All samples must be quantified within the calibration range Method Detection Limits (MDLs) are calculated and reported annually - Since 1989, method for calculating MDLs is that used by the EPA If EPA method is not used - the procedure is described in detail
			Major and trace elements: Si, Al, Fe Cr, Zn, Mn Ag, As, Cd, Cu, Ni, Pb Hg	 FAA FAA, GFAA GFAA, FAA, HAA CVAA	Ag, Cd, Hg = 0.005 ug/g Cr, Pb = 0.2 ug/g As, Cu = 0.05 ug/g	
			Clostridium perfringens TOC Moisture content Particle size	plate count CHN analyzer drying at 120 degrees C Wet sieving techniques		
			Fish Tissue: Organic compounds: Pesticides, PCBs PAHs - stomach contents PAH metabolites - bile	 GC/ECD GC/FID/MS HPLC/FID	 0.001 ug/g 0.01 ug/g 0.01 ug/g	Precision - defined limits Accuracy - defined limits A minimum of 8% of an analytical sample string should consist of blanks, reference or control materials, duplicates, and spike matrix samples
			Major and Trace elements: Al, Ag, As, Cd, Cr, Ni, Pb, Sb, Se, Sn, Tl Fe, Mn, Cu, Zn Hg	 GFAA GFAA FAA CVAA	Ag, Cd, Hg = 0.001 ug/g Cr, Pb = 0.04 ug/g As, Cu = 0.01 ug/g	Data acceptability criteria reported annually Intercomparison exercises Quality assurance workshops Development of standard reference and control materials
			Tissue dry weight *Otoliths or scales - fish age*	Oven drying		
2. Mussel Watch Program (MWP) (NOAA, 1993)	6 Stations: Sites were defined using Global Positioning System Technology	When taken, sediment samples were collected concurrently with bivalve samples Sediments: - stainless steel box core - Teflon-coated sampling scoop Oysters: American oyster - hand (preferred), tongs, or dredge	Water: probe Temperature, salinity, depth			National Institute of Standards and Technology (NIST) trace organic exercises - performance based National Research Council (NRC) trace element exercises - performance based
			Sediments: Organic compounds: Pesticides, PCBs PAHs Coprostanol	 GC/ECD GC/MS GC/FID	 0.0001 ug/g 0.0010 ug/g	
			Major and trace elements: Al, Cr, Mn, Fe Ni, As, Se, Ag, Cd, Sn, Pb Cu Zn Hg	 NAA GFAA GFAA, FAA FAA CVAA	Ag, Cd, Hg = 0.005 ug/g Cr, Pb = 0.2 ug/g As, Cu = 0.05 ug/g	
			Clostridium perfringens TOC Moisture content Particle size	plate count carbon analyzer 24 hours at 45 degrees C Dry sieved		
			Oyster tissue: Organic compounds: Pesticides, PCBs PAHs	 GC/ECD GC/MS	 0.001 ug/g 0.01 ug/g	

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
			Major and trace elements: Al, Mn, Fe, Zn Cu Cr, Ni, As, Se, Ag, Cd, Sn, Pb Hg Tissue dry weight Shell size Radionuclide samples - 1991 Gonadal index	 FAA FAA/GFAA GFAA CVAA Oven drying	Ag, Cd, Hg = 0.001 ug/g Cr, Pb = 0.04 ug/g As, Cu = 0.01 ug/g	
National Marine and Fishery Service (NMFS) (Zimmerman, 1993)						
1. Baseline Production	Variable stations in West Bay marsh	Fish, shrimp, and crabs are sampled using drop samplers	Organisms: Densities of target species Biomass			
2. Brown Shrimp Catch Program		NMFS - brown shrimp - Interviews with bait dealers and fishermen - Reviews of fishermen's logs	Catch per unit effort Pounds per hour			
3. Post Larval Shrimp Program (discontinued in 1993)	6 Stations	Samples are collected with a 5' long, small-meshed, modified hand-held beam trawl	Water: probe Temperature, salinity Tide condition Catch per 100 square meters of bottom area Length (size of shrimp)			
Texas Department of Health (TDH) (APHA, 1970) (Wiles, 1993)	104 Stations - approved shellfish harvest areas - conditionally approved waters	Water samples are collected 2 feet under the water surface while other parameters are measured by probes.	Water: probe Temperature, DO, salinity Weather conditions: Air temperature Rainfall Wind direction Wind velocity Tide conditions FC			National Shellfish Sanitation Program NSSP QA/QC Guidelines (9)

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
U.S. Army Corps of Engineers (USCE) 1. Dredged Material Monitoring Program Galveston District (Medina, Hauch, and Arhelger, 1993) (U.S. EPA, 1986 and 1991)	6 core stations in the Houston Ship Channel	Samples collected by a bottom grab	Heavy Metals As Cd Cr Cu Ni Pb Zn Se Hg Oil and grease PCBs PAHs Pesticides Grain-size analyses Toxicity Bioaccumulation	EPA methods (2) 7060 7131 7191 7211 7521 7421 7951 7740 7470 10-day solid phase bioassay 28-day bioaccumulation		Dredged Material Testing Manual QA/QC Guidelines (10) - 10% of laboratory samples are field duplicates - One sample of every 10 - 20 samples are analyzed in triplicate
2. Open Bay Disposal Dredged Material Program - Waterways Experiment Station (3 year program scheduled to finish in 1994) (Clark and Ray, 1993) (U.S. EPA, 1986 and 1991)	30 Stations: Open Bay	Samples collected with a box corer Sediment profiler	Sediment: Sediment profile imagery Grain-size analyses Sediment carbon Redox potential Surface relief Benthos parameters	EPA methods (2)		Dredged Material Testing Manual QA/QC Guidelines (10)

NOTES:

(1) U.S. EPA. 1983. Methods for chemical analyses of water and wastes, 2nd Edition. EPA 600/4-79-020. U.S. Environmental Protection Agency, Environmental Support Laboratory.
(2) U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes, 3rd Edition. EPA SW-846. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.
(3) TNRCC. 1993. Quality Assurance Project Plan for Environmental Monitoring and Measurement Activities, Surface Water Monitoring. Texas Natural Resource Conservation Commission, September 1993.
(4) TPWD. 1993a. Marine Resource Monitoring Operations Manual. Texas Parks and Wildlife Department, January 1993.
(5) TPWD. 1989. Commercial Harvest Field Operations Manual. Texas Parks and Wildlife Department, January 1989.
(6) TPWD. 1993b. Marine Sport Harvest Monitoring Operations Manual. Texas Parks and Wildlife Department, July 1993.
(7) APHA. 1992. Standard Methods for the Examination of Water and Wastewater, 18th Edition. American Public Health Association, Washington, D.C.
(8) APHA. 1989. Standard Methods for the Examination of Water and Wastewater, 17th Edition. American Public Health Association, Washington, D.C.
(9) APHA. 1970. Recommended Procedures for the Examination of Seawater and Shellfish. American Public Health Association, Washington, D.C.
(10) U.S. EPA. 1991. The Near Coastal Laboratory Procedures Manual. Environmental Monitoring and Assessment Program. U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Cincinnati, OH.

** ABBREVIATIONS:

AES - Atomic emission spectrometry
CGC - Capillary gas chromatography
CHN analyzer - Carbon-hydrogen-nitrogen analyzer
CVAA - Cold vapor atomic absorption
DCP - Direct coupled plasma
ECD - Electron capture detection
FAA - Flame atomic absorption
FID - Flame ionization detector
GC - Gas chromatography
GC - Gas chromatography
GFAA - Graphite furnace atomic absorption
HAA - Hydride generation atomic absorption
HPLC - High performance liquid chromatography
ICP - Inductively coupled plasma
MS - Mass spectrometry
NAA - Neutron activation analysis
SIM - Selected ion monitoring

established methods; sampling and analytical equipment are already available, data analysis procedures are established, and field and analytical staff do not require additional training.

Appropriate analytical sensitivity of routine monitoring methods has been cited as an essential criterion for agencies in the performance of their mandated responsibilities. Accuracy and precision of analytical methods are also important criteria so closely linked to sensitivity that the three criteria must be considered together. Sampling or analytical methods must be sufficiently sensitive and precise, and the data sufficiently accurate to detect both seasonal variability and long-term trends in the monitored parameters.

The robustness or adaptability of a monitoring method is an essential characteristic when considering a long-term regional monitoring effort. A sampling method that cannot be employed with consistent results throughout the monitored region or under the normal range of environmental conditions cannot be used effectively in a regional program. The same is true for analytical methods that may be subject to degradation of sensitivity, accuracy, or precision from chemical or biological interference mechanisms that may be encountered.

1.3 DOCUMENT LAYOUT

The Regional Monitoring Protocols are composed of several major monitoring components identified by the GBNEP program office and described in the Comprehensive Conservation and Management Plan (CCMP). One extra topic has been added to these six components. This addresses the recommended protocols for sample station positioning, i.e., how the latitude and longitude of each sampling event are determined. This topic is discussed before all the others because it applies directly ands equally to all field sampling efforts undertaken for the Regional Monitoring Program, regardless of whether sample collection or monitoring observations are conducted from a vessel, on land, or from the air. The monitoring protocols are organized into these components:

- Station positioning
- Water quality (which includes the topic Hydrodynamics)
- Sediment quality
- Habitat protection
- Species population protection
- Public health protection.

The specific Resource Management Objectives that are directly or indirectly related to each major monitoring component and that can be supported by environmental monitoring efforts are identified at the beginning of the description for each recommended monitoring activity.

Table 1-2. SELECTION CRITERIA FOR MONITORING PROTOCOLS

- **Comparability**—the measure of whether data collected by the method is directly comparable to existing data for the same parameter

- **Cost**—the combination of implementation, equipment maintenance, and per sample costs

- **Sensitivity**—the measure of the ability to detect target parameters at low levels, sufficient to distinguish between seasonal variability and long-term trends.
- Accuracy—the measure of the agreement between the amount of a component measured and the amount actually present

- **Precision**—the measurement of the reproducibility of results when a method is repeated using a homogeneous sample under controlled conditions, regardless of systematic or constant errors that may affect the accuracy of the method.

- **Robustness**—the measure of method adaptability to the range of seasonal environmental conditions experienced across the estuary and to the range of expected target contaminant concentrations and non-target interference matrices and mechanisms.

The Protocols described in this document address only sample collection and sample analysis efforts designed to measure ambient conditions. The document is not intended to discuss monitoring strategies, such as sampling frequency, sample collection locations within the bay, sampling density throughout the bay, sampling segmentation regimes, or the delineation of "hot-spots." These monitoring strategy issues are discussed in the *Galveston Bay Regional Monitoring Strategy* (Tetra Tech, 1994) and the draft *Galveston Bay Regional Monitoring Program* (GBNEP, 1994).

A chapter is devoted to each of the six major components. Where appropriate, each chapter is divided into sections, each devoted to a single parameter for which a monitoring protocol is recommended. Specific parameters and/or indicator species, proposed by the Monitoring Steering Committee participants, are listed. The discussion of each monitoring protocol is further divided into the following sections and descriptions, when appropriate:

- **Data use and limitations**
  - Discusses the Resource Management/CCMP Objectives that are directly supported by this specific monitoring effort
  - Discusses those Resource Management/CCMP Objectives that are partially supported by this specific monitoring effort
  - Discusses Agency mandates or objectives for which this monitoring effort is performed

- Describes information provided by the monitoring effort including a description of how the data is used.

- **Sampling and analytical methods**
  - Identifies methods used for existing monitoring programs and special studies
  - Recommends and outlines a preferred method and equipment for sample collection
  - Recommends a preferred method and equipment for sample analysis.
  - Includes full citations and references for all published protocols, and agency contacts for unpublished protocols
  - May include a description of ancillary data to be collected
  - May include a description of an available alternate monitoring method

- **QA/QC considerations**
  - Describes QA/QC conducted under existing programs for sample collection and handling
  - Describes QA/QC conducted under existing program for sample analysis
  - Recommends changes/additions to QA/QC as required to meet needs of the Regional Ambient Monitoring Program.

All recommended sampling and analysis protocols are derived from existing methods used by the various agencies with resource monitoring and protection responsibilities within the Galveston Bay estuary. Thus, descriptions of methods are either referenced by citing the appropriate procedures manuals, or summarized directly from existing agency operations/protocol manuals when such documents are not widely available. Other methods, not formally committed in writing (or at least, not identified in a written format, are described in more detail. In the case of suggested alternate methods, descriptions of protocols have been based on methods used in special studies conducted within Galveston Bay or methods used in other estuarine studies or monitoring programs.

Because of the diverse sources of information and the wide range of environmental parameters addressed in these monitoring protocols, the level of descriptive detail varies between different sections of the document. However, in all cases, all existing documented methods and all sources contacted (personal communications) are cited and fully referenced. It is hoped that this information will be sufficient to assist the reader in gathering further information on any of the monitoring methods for which he has an interest.

This draft document can be considered a basic staging point for the Regional Monitoring Program. The selection of methods has been accomplished with guidance from the five Monitoring Steering Committee focus groups. The information presented is expected to evolve in both content and level of detail in response to continued review by and suggestions from Committee members. The final version of this document will be published in a loose-leaf format. This will facilitate revisions and updates to specific collection and analytical methods as new techniques and variations in monitoring strategies are developed.

CHAPTER 2
STATION POSITIONING

This section addresses the process of positioning a sampling vessel on a station during field sampling. The process of locating the sample collection point from a boat has traditionally involved use of a fixed marker of some type. These are generally navigation aids or oil platforms or, in the case of a narrow channel, a shore marking. One consequence of this positioning procedure is that, to some degree, stations tended to be confined to more heavily used areas, and open bay locations tended to be under-represented in the sampling.

With the advent of relatively inexpensive LORAN and Global Positioning Systems (GPS) electronic navigation systems, which are capable of quite high accuracy if necessary, there is no longer any field need to be restricted to fixed marks. It is useful, however, in the human communication process to be able to refer to commonly known locations. The ability to select a location (latitude/longitude) without having to be near a fixed mark should make the station positioning process more flexible.

2.1 DATA USE AND LIMITATIONS

The primary functions of station positioning are to properly locate the sample collection point in the field and to properly record the sample collection point in the data record. While traditional monitoring efforts have found it convenient to merely identify a station by a name, with geographic coordinates stored separately, the advent of Geographic Information Systems (GIS) and ease of spatial plotting makes it desirable to have coordinates stored directly with the station data.

Having the information on position in a form suitable for direct plotting raises the need to consider the type of use and the need to have data storage consistent with positional accuracy. For example, generally no great positional accuracy (e.g., +/- 500 m) is necessary for sampling in an open bay to characterize ambient water or sediment conditions for routine purposes. On the other hand, it is possible that monitoring that has a legal or enforcement purpose may have very different positioning needs. For this discussion, it is assumed that all monitoring for the Galveston Bay Program will be limited to non-legal purposes.

With the advent of smaller and cheaper positioning systems, monitoring crews can improve sample positioning with little additional effort. A single, stand-alone GPS unit is capable of a precision of better than ±100 meters when receiving the standard Coarse/Acquisition (C/A) code.

2.2 RECOMMENDED METHODS

All sampling crews should be equipped with a portable GPS receiver that has both a visual display and provision for digital transfer of coordinates to any of a number of data logging systems or a portable computer. The position should be recorded digitally as well as on paper from the visual display at the approximate midpoint of data collection at a station. If the nature of the data collection is to extend over a longer time or distance (e.g., a trawl), the position should be recorded at the beginning of the activity, at fixed intervals during the activity and at the end of the activity.

USEPA has published a reference that provides an overview of GPS survey methods and procedures, from initial planning to data reduction and postprocessing:

> *GIS Technical Memorandum 3: Global Positioning Systems Technology and Its Application in Environmental Programs.* EPA/600/R-92/036. EMSL, Las Vegas. U.S. Environmental Protection Agency, 1992.

2.3 QA/QC CONSIDERATIONS

As with any mechanical or electronic system, it is important that the human operators monitor performance and maintain a check on accuracy. In the case of an electronic latitude-longitude readout, the vessel operator should always monitor the position of the vessel relative to visual landmarks and aids to navigation, and check to see that the electronic readout is approximately correct. In addition, it is important to perform accuracy checks with each sampling trip. These would consist of checking the latitude-longitude of a known position at the beginning and end of each sampling trip. If there is a significant departure of the known position, the difference must be recorded and measures taken to correct the position data collected during the trip.

2.4 ALTERNATIVE METHODS

Improved positioning can be obtained by using differential techniques. These methods require a second receiver to be recording at a known reference point to compensate for the errors inherent in the satellite positioning data. Error correcting messages can be sent in real-time via a radio link between the two GPS units to continuously update the mobile unit. Another alternative is to record the corrections and apply them after the survey is completed. In this case the radio link between the reference and mobile GPS units would not be necessary. The potential accuracy for these differential methods can range between 1.0 - 10.0 meters, with 3 - 4 meters being the usual range (EPA, 1992). U.S. Coast Guard plans for establishing a network of differential GPS reference stations around the coast may provide a third and more convenient alternative to differential GPS usage.

In addition to the advantage of flexibility in site selection, using GPS offers an improvement in the data logging and transfer process. Currently, it is generally necessary to enter the station location first on paper in the field log and then to an electronic media via keyboard, along with the various parameter values. Keyboard data entry entails additional labor costs and a certain percentage of entry errors which are inherent in the process. With much of the data being generated from instruments in the field, inclusion of position information directly in the automatic data logging process would increase both monitoring efficiency and reliability.

Obviously alternatives are available. LORAN-C can provide digital information at a slightly lower cost but with a substantial drop in accuracy ($\pm$ 500 m). However, because of the trend of monitoring agencies requiring more stringent accuracy, it is recommended that an integrated GPS/data recording system be the first choice for sampling positioning.

CHAPTER 3
WATER QUALITY

This section addresses water quality considerations. Specific topics included under this broad heading include:

Hydrodynamics or water movement
Water column sampling procedures
Chemical analyses.

The chemical analyses section is further subdivided into the broad and sometimes overlapping groupings of conventionals, nutrients and toxics.

This section generally supports all of the Water and Sediment Quality Goals of the Galveston Bay Program. It should be noted that monitoring tends to lend itself to assessment of goals and objectives rather than specific plan actions.

3.1 HYDRODYNAMICS

The term hydrodynamics means, literally, the movement of water. In this context it refers to tides and currents, as affected by both wind, freshwater inflows and lunar/solar gravitational fluctuations (astronomical tides). One of the purposes of having hydrodynamic data is to facilitate the interpretation of water quality data. For example, if the TSS concentrations on a given day were higher than typically observed at a station, it may be because the wind was unusually high, resulting in larger than normal waves which re-suspended bottom sediments, or it may be because of some other reason such as recent rains and high freshwater inflows or a phytoplankton bloom. Resolving this point could be quite important in determining if a trend could be detected. A similar statement could be made for nutrient or salinity concentrations, which could be strongly influenced by the state of the tide.

3.1.1 Data Use and Limitations

Monitoring data on the hydrodynamics within the bay can provide information to be used in support of the assessment of the following Resource Management Objective:

FW-4: Complete an evaluation of bay circulation patterns and their effects on bay habitats and species by 1999.

The present monitoring procedures in Galveston Bay provide for very specialized approaches to hydrodynamic data collection, but little or no activity in this regard is performed in the routine programs of the TNRCC and local agencies. For example, there is a tide gage network active along the Texas coast with eight stations located in Galveston Bay (the Texas Coastal Ocean Observation Network, TCOON, operated by the Conrad Blucher Institute in conjunction with the TWDB), as well as tide gages operated by the National Ocean Survey (NOS) and the Corps of Engineers (COE). However, no procedures are in place for recording the tide level when a sample is collected. There is no ongoing program to record currents in the bay, although the COE and other agencies, including NOAA-NOS, have performed short-term current monitoring studies over the last several years.

The TWDB operates five permanent continuously recording stations for water quality data collection to support their modeling programs for circulation and salinity. Freshwater inflow gaging stations are largely supported by the U.S. Geological Survey (USGS) and some local entities such as cities and river authorities. Rain gages and wind data collection are supported by the National Weather Service as well as airport authorities and cities. All of these sources together provide sufficient data to estimate the currents in the bay, with an accuracy which is sufficient for all routine purposes. While none of these data sources exist to support the Galveston Bay Program management goals, they all provide essential support to the full range of goals and objectives.

3.1.2 Sampling and Analytical Methods

As the primary need for hydrodynamic information is to aid in the interpretation of other water quality data, and because there is already an established data collection network in place, the approach recommended is to incorporate this network into the overall Galveston Bay Regional Monitoring Program (GBRMP) by reference. Assessing currents will not be considered as a monitoring element for the GBRMP. The principal benefit that the GBP can provide is to facilitate the linking of the various data sources which would allow ready use of the data in support of GBP goals.

Alternative Methods

In theory it would be possible for the agencies with a water quality responsibility to begin their own collection programs for hydrodynamic data. While this is possible, it is not recommended as it would be duplicative and wasteful. However, the need for surveys to assess specific problems associated with bay circulation, especially those involving in-bay construction or shoreline alterations, either man-made or natural may arise. It is recommended that a study plan be devised to establish baseline conditions and post-construction altered flow patterns in the case of planned construction or alteration, once the location and extent of the planned project is known.

3.1.3 QA/QC Considerations

All of the agencies involved in hydrodynamic data collection have their own programs in this area. Because no effort is recommended to modify the agency data collection programs, existing agency QA/QC procedures are recommended. In the case of the need for a special study, as discussed above, QA/QC procedures pertinent to the proposed study (i.e., types of measurements, types of instrumentation) would need to be specified as part of the study plan.

3.2 WATER COLUMN SAMPLING

Monitoring water quality in the Galveston Bay estuary will provide data necessary to directly assess or support attainment of the following Resource Management Objectives:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014

WSQ-2: By 2004, ensure that all water quality segments within the estuary are in compliance with established dissolve oxygen criteria

Almost all monitoring involves locating a probe in the water column or the collection of samples at various depths for analysis. This section addresses the process of selecting the point(s) in the water column to sample and the methods of collecting the samples.

3.2.1 Data Use and Limitations

The *Texas Surface Water Quality Standards* (Section 307.9) specify sampling procedures for determining standards attainment. For bacterial and temperature comparisons, water column sampling involved collecting the sample one foot below the surface in all cases. However, for other *Standards* parameters (e.g. DO, pH, TDS) the collection depth varies depending on the type of water body. For well-mixed non-tidal streams, the one foot depth is sufficient. For vertically stratified non-tidal streams, bays and tidal streams a surface to bottom depth-integrated sample is specified. However, for bays the definition is the "natural" bottom, excluding dredged areas. In the case of tidal streams, if density stratification occurs, only the data in the "mixed surface layer" are to be used to determine standards attainment. Aquatic toxicity criteria apply to any single sample while human health criteria apply to the vertical average of water column samples.

3.2.2 Sampling and Analytical Methods

There are two basic types of sampling to be addressed. One is where a single sample can be used to represent the water column and the other is where multiple observations must be taken to obtain a vertical profile. The first is used when the water column is vertically homogeneous and the second when there are vertical differences. A second issue is the intervals to be employed when doing a vertical profile of the water column.

There are two techniques for collecting a depth-integrated sample. One is compositing discrete samples collected at various depths. The other is the depth-integrated sample collected via a continuously running submersible pump. The pump is lowered to the bottom and raised at a constant rate, with the discharge collected in a clean container. The water in the collection container becomes a depth-integrated sample, which can be subsampled.

These two techniques are virtually equivalent when used to monitor shallow estuaries, differing primarily in the amount of time and type of equipment required. For example, the submersible pump attached to the probe assembly can readily be used to generate a depth-integrated sample by careful control of the lowering and raising procedures. Water bottle samplers generally consist of a cylindrical tube with stoppers at each end and a closing device that is activated from the surface by a messenger or an electrical signal. The most commonly used samplers of this kind are the Kemmerer, Van Dorn, and Niskin samplers. These devices collect a discrete sample of water at any designated depth.

Recommended Methods

The Galveston Bay Program recommends procedures follow the *Texas Surface Water Quality Standards*, dated July 10, 1991. The Standards, as well as describing sampling depths for different water bodies (non-tidal streams, impoundments, bays, and tidal streams), also reference collection and preservation procedures set forth in the most recently published *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).

The use of pumped water systems for either discrete or continuous water sampling is the most common method and is recommended for all but trace metal samples. All tubing should be thoroughly flushed through with the sample water before a sample is taken for analysis. Especially in relatively shallow estuarine areas, such pumped water systems are very convenient to use and are less expensive than a set of discrete water samplers.

A dedicated and specially cleaned peristaltic pump with in-line disposable filters can be used for metal samples. This method is recommended in the TWC (now TNRCC) manual:

> *Water Quality Monitoring Procedures Manual Draft*, June 1993.
> Water Quality Monitoring Team, Texas Water Commission (TWC, 1993).

However, due to the relative ease with which trace metal sample contamination can occur, discrete water samplers are highly recommended for these samples and are essential for any ultra-clean procedures. The recommendation for discrete sampling is simply that the pump system proposed for all other parameters, a high volume-low head pump (e.g., bilge pump), does not meet the ultra-clean requirements for metals sampling. A peristaltic pump, with suitably clean tubing and separation from other potential sources of contamination, could be employed for this purpose.

The most suitable containers for the collection, processing, and storage of trace metal samples are made of quartz or fluoropolymers such as polytetrafluoroethylene (PTFE) and tetrafluoroethylene (TFE). Care should be exercised to avoid contamination of the sampler as it passes through the surface layer during deployment and retrieval. The sampling vessel should be positioned so that the sample bottle can be deployed outside the possible influence of the vessel. As with all parameters, once the water sampler is brought on board the sampling vessel, the stoppers should be checked to see if any leakage has occurred. If a stopper is not properly sealed, water from the sampled depth may have leaked out during retrieval and been replaced by water from shallower depths. In such cases, the entire water sample should be rejected.

When collecting a depth-integrated sample, a continuous profile is, in theory, the most representative. However, for probe measurements it is not practical to record data continuously. Three-meter (10-ft) intervals are currently used by the TNRCC in navigation channels and would continue to serve as an adequate basis of information. Measurements at a finer resolution are easily obtained through the use of automated probes and data loggers, but do not seem practical when considering the cost of additional samples and data storage.

Alternative Methods

The use of discrete samplers or pumps can be determined by the sampling purpose, given that sample contamination concerns are adequately addressed in all cases. Other satisfactory sampling methods that have been used in Galveston Bay include a pressure driven sewage sampler and submerging a sample container by hand to obtain near-surface samples. Again it is important that quality and contamination concerns are properly addressed.

3.2.3 QA/QC Considerations

Since some types of sample results can be greatly affected by sample contamination, appropriate precautions should be taken to avoid contamination at every stage of sample collection, handling, storage, preparation, and analysis. Prior to use, sampling and laboratory equipment must be cleaned as needed for the particular sample type. For example, water sampling bottles that are used to collect samples for measurement of ambient metal concentrations must not contain metal or rubber parts that may contaminate the water sample.

In the field, sources of contaminants could include sampling gear, lubricants and oils, engine exhaust, airborne dust, tobacco smoke, and ice used for cooling samples. During sample handling, preparation, and analysis, samples may become contaminated from exposure to airborne dust, insufficiently clean sample containers, contact with inappropriate materials, contaminated reagents, and carry-over in testing instruments due to insufficient cleaning or flushing between samples. Field personnel can also contribute directly to sample contamination. Field and trip blanks should be run to detect any outside sample contamination.

The *Texas Surface Water Quality Standards* refer to the *Standard Methods* (APHA, 1992) for QA/QC procedures for sample collection and preservation. The TWC (now TNRCC) draft *Water Quality Monitoring Procedures Manual* (TWC, 1993) also provides specific QA/QC procedures for water sampling.

3.3 CONVENTIONAL PARAMETERS

The term "conventional" in a water quality context has evolved over the last decades to distinguish between more specialized types of parameters, but has itself no clearly defined meaning. For this methods manual, it will be considered to include the following water column parameters:

- Dissolved Oxygen (DO, probe)
- Oxygen Demand: BOD5 and CBOD5; COD
- Total Organic Carbon (TOC)
- Salinity or Total Dissolved Solids (conductivity, probe)
- Hardness (if salinity < 2ppt)
- Chlorides and Sulfates (if salinity < 2ppt)
- pH (probe)
- Temperature (degrees C)
- Total Suspended Solids (TSS)
- Volatile Suspended Solids (VSS)
- Fecal Coliform (FC) bacteria

Most of these parameters are routinely monitored by the TNRCC, as well as federal, City of Houston, and County agencies.

3.3.1 Data Use and Limitations

The Resource Management Objective addressed directly by monitoring conventional water quality parameters is:

WSQ-2: By 2004, ensure that all water quality segments within the estuary are in compliance with established dissolve oxygen criteria.

A second Objective that is partially supported by this monitoring is:

PH-3: By the year 2000, establish a contact recreation advisory program in all areas of the estuary used for contact recreation.

Conventional parameters are useful in characterizing a water body and can aid in the interpretation of other types of water quality parameter data. However, not all of the parameters listed are routinely analyzed under current monitoring programs.

For example, during most of the 20th century, a primary water quality concern was DO level as influenced by wastewater Biochemical Oxygen Demand (BOD) inputs. Accordingly, surface water samples have routinely been analyzed for BOD as if they were wastewater, using the multiple dilution technique specified in *Standard Methods* (APHA, 1992). Even up to ten years ago, it was common practice to run BOD analyses on bay water samples. As the level of wastewater treatment has increased, the effect of point sources on even tributaries to the bay BOD levels has become, in general, insignificant. Whatever anthropogenic source there may be is lost in the background BOD level of 1-4 mg/L produced by normal water column biochemical processes. Accordingly, the TNRCC has ceased performing BOD or CBOD (Carbonaceous BOD) analyses on bay water samples. A similar statement can be made for the Chemical Oxygen Demand (COD) test. However, in this case there is another reason to delete the test, namely the effect of chloride interferences on the COD test results.

The FC parameter is also subject to extreme variation in uses and analytical methods. There are two basic test methods for producing an FC result for a water sample. One is used by the Texas Department of Health (TDH) to regulate oyster harvesting waters and the other is used by all other agencies, primarily for detecting human health problems and addressing contact recreation concerns. Numerous studies (e.g., Jensen and Su, 1992) have confirmed that the two tests provide essentially equivalent information, yet the TDH, as mandated by the National Shellfish Sanitation Program, only accepts one of the methods (the one that is much more costly). The net effect is that the FC monitoring effort is somewhat inefficient.

As noted earlier, the primary use of the conventional parameters is general water quality characterization, including determining compliance with applicable criteria. Many agencies collect conventional water quality parameter data, generally as a part of their overall mandates. For example, the TNRCC monitors for several reasons including determination of criteria attainment and providing data for a report mandated by Section 305b of the Clean Water Act. Other agencies analyze conventional parameters for reasons such as identifying possible pollution problems or as a general characterization.

Another use of the conventional data is in providing information on trends of key parameters such as salinity, DO, or TSS. This trend information is quite useful in adjusting management directions and can play a major role in agency decision making. The ability to detect trends is strongly dependent on the number and frequency of observations, as well as the methods employed.

3.3.2 Sampling and Analytical Methods

By and large, the methods recommended for the conventional parameters are those which are currently employed by the many agencies involved. This is because there is already a great deal of experience in monitoring conventional parameters. DO, Temperature, pH, and conductivity/salinity are recommended to be measured with a probe, with a calibration check at the beginning and end of the sampling run. For laboratory analyses, Table 3-1 lists the recommended methods to be used. Changes

Table 3-1. COMPARABLE AND ACCEPTABLE LABORATORY ANALYTICAL METHODS FOR CONVENTIONAL WATER PARAMETERS*

Parameter	EPA Method	Standard Methods
CBOD5	405.1	5210
TSS	160.2	2540 D
VSS	160.4	2540 E
TOC	415.1	5310 B,C
Hardness	130.1, 130.2	2340 C
Chloride	325.3	
Sulfate	375.4	
FC		9222 D

* Parameters not measured by *in-situ* probe

and standardization of procedures would be required for some agencies, but the changes proposed are not large. It is expected that further evolution of methods will occur in the future.

Alternative Methods

There is at least one alternate approach or modification discussed which would serve to unify the data collection and integration process. The suggested alternative deals with the use of probe data logging, which would include time, depth, position (latitude/longitude) from a GPS unit, and the standard probe parameters. Additional parameters currently described under nutrients and phytoplankton monitoring (light via photometer and chlorophyll-*a* via fluorometer) could readily be added to the sampling probe system. With all of the data being recorded in a standard format, it would greatly facilitate the process of getting the data into a usable database. The capability of integrating the data collection, positioning and recording processes is relatively new and not commonly employed. However, it is well within the capability of commercially available equipment.

3.3.3 QA/QC Considerations

The QA/QC procedures recommended for monitoring conventional water quality parameters as part of the Galveston Bay Regional Monitoring Program are described in:

> *Quality Assurance Project Plan for Environmental Monitoring and Measurement Activities, Surface Water Monitoring.* TNRCC, 1993.

They include requirements that 10% of samples be used for field duplicates and that strict field instrument calibration procedures be followed.

Quality control specifications for ambient water analyses have been incorporated into state law (*Texas Surface Water Quality Standards* Section 319.1 - 319.12).

These QC procedures (Table3-2.) are designed to satisfy EPA's National Pollution Discharge Elimination System (NPDES) monitoring program requirements. All laboratories performing NPDES work are required to use these QC procedures. It is recommended that, at a minimum, the QC standards for all Galveston Bay Regional Monitoring Program-related water, sediment, and tissue analyses also meet these legislated specifications.

3.4 NUTRIENTS

The elements which are intimately involved in biological processes, namely nitrogen (N), phosphorus (P), and silicon (Si), are usually considered separately as nutrient or macro-nutrient elements. While nitrogen is generally the chief limiting element to primary production in estuaries, phosphorus may be limiting during certain seasons of the year in some systems. Silicon is chiefly required by floral groups that secrete siliceous skeletons, but may be required by other aquatic plants as well. Silicon is most likely to have the potential to be limiting in lake systems or deeper bays such as Puget Sound. In relatively shallow Galveston Bay where sand and silicon containing minerals are in contact with the water, silicon is not likely to limit plant growth and therefore is not recommended as an indicator.

The concentration of nitrogen and phosphorus varies both spatially and temporally depending partly on the extent of plant growth and local inputs. Light transparency is another major factor involved in primary production in estuaries. In the ocean, below the depth at which plant growth is restricted by insufficient light, nutrient concentrations tend to be much higher and more uniform although there are significant variations in the different oceanic basins (Head, 1985).

The Galveston Bay Program candidate indicators for nutrients include the following parameters:

- Nitrogen
  - Ammonium–N
  - Nitrate-nitrite–N
- Phosphorus
  - Total
  - Ortho-phosphate
- Light penetration

Organic nitrogen (Total Kjeldahl N minus ammonium–N) is not considered for routine nutrient monitoring, although it is recommended to be measured in some samples. The phosphorus suite includes measurements of dissolved total phosphorus. With some samples, dissolved orthophosphate (PO_4^{3-}) should be analyzed. At some interval, a parallel set of unfiltered analyses should be performed. The candidate indicator for light penetration will be Secchi disk depth (see alternative methods).

Table 3-2. REQUIRED QUALITY CONTROL ANALYSIS

Parameter	Blank	Standard	Duplicate	Spike
Bacterial	A			B
Alkalinity			A	B
Ammonia Nitrogen	A	A	B	B
BOD	A	A	B	
BOD-Carbonaceous	A	A	B	B
Chloride	A	A	B	B
Cyanide-(total or Amenable to Chlorination)	A	A	B	B
pH		C		
Metals (all)	A	A	B	B
Nitrate Nitrogen	A	A	B	B
Nitrite Nitrogen	A	A	B	B
Orthophosphate	A	A	B	B
Oxygen (dissolved)		A	B	
Phosphorus-Total	A	A	B	B
Specific Conductance	A	A		
Sulfate	A	A	B	B
TOC	A	A	B	B
TSS	A		B	
TDS	A	A	B	
Organics by GC or GC/MS	A	A	E	E

A -Wherever specified, at least one blank and one standard shall be performed each day that samples are analyzed.

B -Wherever specified, duplicate and spike analyses shall be performed on a 10% basis each day that samples are analyzed. If one to 10 samples are analyzed on a particular day, then duplicate and one spike analysis shall be performed.

C -For pH analysis, the meter shall be calibrated each day that samples are analyzed using a minimum of two standards which bracket the pH value(s) of the sample(s).

D -For the oil and grease analysis and chlorine-total or free analysis, standards shall be analyzed on a 10% basis. If one to 10 samples are analyzed in lieu of standards for the oil and grease analysis and chlorine-total or free analysis.

E -For GC and GC/MS analyses, duplicate and spike analyses shall be performed on a 5% basis. If one to 20 samples are analyzed in a month, then one duplicate and one spike analysis per month shall be performed.

Source: *Texas Surface Water Quality Standards* - Sections 319.1 - 319.12

There are currently six agencies measuring nutrients in or near Galveston Bay. A summary of regional monitoring activities for Galveston Bay including agencies, data collection activities, parameters, methods, and QA/QC is presented in Table 1-1. TNRCC has the most comprehensive nutrient monitoring program involving 68 stations located throughout the bay. TNRCC routinely measures ammonium–N, nitrite–N, nitrate–N, total phosphorus, and orthophosphate. The City of Houston, Department of Public Utilities, currently measures ammonium–N in the tidal portions of major bayous in the Houston vicinity. The City of Houston, Health and Human Services Department, routinely measures ammonium-N and nitrate–N in streams in the Houston area. Although this monitoring effort is a significant one, the stations are all above tidal waters. The Harris County Pollution Control Department currently monitors ammonium-N at nine Houston Ship Channel stations, six San Jacinto River stations, and industrial and municipal dischargers. The Galveston County Health District monitors 120 stations in or near Galveston Bay at which they occasionally measure ammonium–N and total phosphorus.

3.4.1 Data Use and Limitations

The goal of nutrient monitoring is to provide data to assess GBP actions. To this end, the collection of nutrient data partially supports the following Resource Management Objectives:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014

WSQ-2: By 2004, ensure that all water quality segments within the estuary are in compliance with established DO criteria.

Nutrient data can be used to better interpret changes in plant growth and primary productivity. In the absence of another limiting factor such as light, an excess supply of nutrients can result in algal blooms and eutrophication of bay waters. A shortage of nutrients can lead to reduced productivity and decreasing numbers of important species. Monitoring nutrient levels in bay waters will provide information needed to:

- characterize ambient nutrient levels
- explain and identify potential causes for observed changes in plant species composition, growth, and/or distribution
- predict the location and timing of algal blooms or shortfalls.

Nutrient monitoring will also allow an evaluation of whether the following Galveston Bay Program management action is being achieved:

- reduce contaminant concentrations to meet standards and criteria

One of the major limitations of bay monitoring of nutrients is obtaining sufficient observations to adequately characterize a system with large spatial and temporal variations. The Galveston Bay Program monitoring approach, which seeks to involve city and county agencies in addition to the TNRCC is a way to achieve greater sampling density.

3.4.2 Sampling and Analytical Methods

A special study by Ward and Armstrong (1992) was sponsored by the Galveston Bay National Estuary Program to compile data from various organizations and to perform a quantitative assessment of water and sediment quality of Galveston Bay over time. The study characterized the concentrations and distribution of parameters throughout Galveston Bay. In regard to nutrients, the study revealed declines in nitrogen and phosphorus concentrations throughout the bay over the past two decades: total ammonium-N on the order of 0.1 ppm/yr, total nitrate-N on the order of 0.01 ppm/yr, and total phosphorus on the order of 0.05 ppm/yr. This decline in nutrients is a concern to the estuarine ecosystem. Ward and Armstrong (1992) suggest that the total suspended solids (TSS) decline is caused by an overall reduction of loading to the bay. They feel this resulted from more advanced waste treatment, entrapment within reservoirs, and changing land use. Because nitrogen and phosphorus have an affinity for fine-grain particulates, their declines may be due to the same causes. This study emphasizes the importance and provides the foundation for further scientific study of nutrients in Galveston Bay.

Recommended Methods

The current methods for nutrients incorporated by the various agencies monitoring in Galveston Bay include:

> *Methods for Chemical Analyses of Water and Wastes.* EPA 600/4-79-020. Cincinnati, OH. US Environmental Protection Agency, 1983, and
>
> *Standard Methods for the Examination of Water and Wastewater.* APHA, 1992.

As mentioned, TNRCC conducts the most extensive nutrient monitoring in which they utilize USEPA (1983) methods.

The sampling of Bay waters for nutrient analysis presents no particular problems if normal standards of cleanliness are maintained. Samples should be collected in glass or plastic containers with leak-proof caps. If plastic containers are used more than once, they should be acid-washed to remove bacteria. In the field, samplers and containers should be thoroughly rinsed with water similar to that to be sampled before each sample is taken. These precautions are particularly important in estuaries, where major changes can occur over relatively short distances and depth ranges (Head, 1985). Samples and sampling containers should not be touched with ungloved fingers. Filtration should be carried out in the field or as soon as possible after collection. Samples can be stored for up to 28 days by cooling at 4° C and adding sulfuric acid to a pH < 2. Nitrate-N samples should be analyzed immediately after collection, or within 48 hours by cooling at 4° C. Water clarity should be measured routinely in the field via photometer or Secchi disk.

The methods recommended in Table 3-3 for the major nutrients are currently employed and generally workable methods. However, they should not be viewed as mandated by the Galveston Bay Program. In fact, the key requirement is that whatever methods are employed can demonstrate the necessary accuracy and precision. If an agency desires to use an alternate method and provides information to the TNRCC supporting this method, there should be no difficulty in substitution.

Table 3-3. COMPARABLE AND ACCEPTABLE LABORATORY ANALYTICAL METHODS FOR NUTRIENT PARAMETERS

Parameter	EPA Method	Standard Methods
Ammonium-N	350.1*, 350.3	4500-NH3 D,F,H
Nitrate-nitrite	353.1, 353.2* 353.3	4500-NO3 C,D E, F
Phosphorus (all types)	365.1, 365.2 365.3, 365.4	4500-P D, E, F

*recommended procedures for NEPs (USEPA, 1992)

Alternative Methods

The possible effects of nutrient limitation as well as excess must be addressed. Therefore, the need for greater sensitivity should be considered. The methods described for nutrients in Parsons et al. (1984) can provide greater sensitivity, as well as precision and accuracy. These methods are currently used in the Puget Sound Water Quality Monitoring Program, but are not used in any existing monitoring effort in the Galveston Bay region. The cost of these more sensitive analyses would be greater than existing methods. However, since there are no commercial laboratories providing this type of service, no direct cost comparison is available.

Another recommendation would involve analyzing unfiltered (i.e., dissolved and particulate) inorganic nitrogen and phosphorus at some interval, such as every 10 samples, for some stations. A greater sensitivity and measurements of the full nitrogen and phosphorus suites would greatly enhance the knowledge of nutrient limitations and provide a foundation for future nutrient quantitative work in Galveston Bay.

The use of an in-situ calibrated photometer for the measurement of light transmission in Galveston Bay should be considered in place of the Secchi disk. The current use of a Secchi disk has several limiting factors. Because Secchi disk readings are dependent upon the available illumination, they vary with cloud cover, cloud formation, and time of day. Secchi disk readings may also vary with the observer because of differences in visual acuity. Thus, to standardize these readings, repeated measurements should be made by one individual under similar conditions of illumination. The Secchi disk is recommended because it is currently being used by the TNRCC and data comparability would be continuous.

Since the regional monitoring plan recommends that primary production be estimated based on known relationships between irradiance and photosynthesis, a more accurate and reliable measurement of light should be considered. A photometer provides a direct reading of light intensity with depth. It could be incorporated into the normal probe package and recorded automatically at little extra cost. Considering the reduced labor cost of avoiding the Secchi disk measurement and manual data entry, it could be a net savings. Absolute light intensity readings should be automatically recorded at the 30-centimeter, 1.5-, and 3-meter intervals with readings at 3-meter increments at greater depth. The result would be far better quality data at little difference in cost. However, an overlap period would be necessary during which both instruments were used to obtain a between instrument calibration.

3.4.3 QA/QC Considerations

The QA/QC procedures for nutrient sample collection and handling as part of the Galveston Bay Regional Monitoring Program are described in:

Water Quality Monitoring Procedures Manual, Draft. TWC, 1993
and

Quality Assurance Project Plan for Environmental Monitoring and Measurement Activities, Surface Water Monitoring. TNRCC, 1993.

In addition, the Galveston Bay Program is planning to organize an annual workshop for agency personnel involved in sample collection activities. This workshop will provide training in standardized sample collection methods and provide an opportunity to disseminate updated methods as they become available. This training will cover collection, preservation, and shipping of routine water quality samples.

At a minimum, analytical QC procedures should meet the NPDES monitoring program requirements as set out in the *Texas Surface Water Quality Standards* Section 319.1 - 319.12 (Table 3-2).

Additions to the existing QA/QC procedures should be considered as presented in:

Monitoring Guidance for the National Estuary Program. EPA 823-R-93-002. US Environmental Protection Agency, 1992.

Calibration standards should be analyzed at the beginning of sample analysis, and should be verified at the end of each 12-hour shift during which analyses are performed (USEPA, 1987). Spike recovery analyses are required to assess method performance for the particular sample matrix. Recommended control limits include 75-125 percent recovery for spikes, and 80-120 percent recovery for the analysis of standard reference materials. A minimum of 5 percent of the analyses should be laboratory replicates. The control limits are +/- 20 percent variation between duplicates. Triplicates should be analyzed on one of every 20 samples or on one sample per batch if less than 20 samples are analyzed.

3.5 TOXIC PARAMETERS

The broad heading of toxic parameters is commonly used to refer to trace metals and organic substances which could possibly exert a toxic effect, if present in sufficiently high concentrations or if present for a sufficient length of time to bioaccumulate to toxic levels.

The candidate indicators for toxic parameters derive from several lists which have been generated by various agencies. Examples include the early "Priority Pollutant List" or the Appendix IX list (40 CFR 264) used in hazardous waste regulation, both produced by EPA, and the parameters specified in the *Texas Surface Water Quality Standards* for Aquatic Toxicity and Human Health protection. The lists can be further subdivided into organic and inorganic portions. The inorganic portion is almost entirely limited to the so-called "trace" metals, i.e., those which exist naturally in relatively low concentrations but if introduced in markedly higher concentrations can have a deleterious effect. The organic substances include both those common industrial organic compounds such as solvents and fuels, and also those compounds designed specifically for a toxic effect, i.e., pesticides.

There are also a number of organic compounds which were not designed for toxicity but still have the effect. Examples would include PCBs and dioxins. Finally, there is a broad class of organic compounds referred to as Polycyclic Aromatic Hydrocarbons (PAHs). Most of these are combustion byproducts and can accumulate in tissue. They can be a concern both from a toxicity and carcinogenicity perspective. Those with less than four aromatic rings tend to be water soluble and relatively toxic (e.g. naphthalene) while the larger molecules (four rings or greater) are not soluble or toxic but have demonstrated carcinogenicity in the laboratory. While not necessarily toxic to marine life, they can pose a human health concern from consumption of the marine life. Most come from combustion sources, and are common in many foods. Those which come from crude oil tend to be those with the smaller number of rings and with more alkyl substitutions on the ring structure.

One of the key concerns with monitoring for toxic substances is the difficulty of detection in the water column. In general it is very difficult to detect and quantify significant concentrations in the water column, unless one is sampling in the immediate area of a point source discharge where the concentrations are unusually high. Because of this limitation, most monitoring for toxic substances is directed at sediments and organism tissues. Examples include NOAA's National Status and Trends Program (NSTP) and the EPA's EMAP program. The oyster is widely used as an indicator organism because it filters large amounts of water and can concentrate toxic substances, particularly those in particulate form, in its tissue. Because many potentially toxic substances tend to sorb to particulate matter, the sediments tend to have higher concentrations, thus allowing easier detection. Monitoring toxic parameters in sediment and tissue is discussed in separate sections of this document. The key point here is that monitoring toxic substances in the water column may not be the most effective approach (i.e., result in any significant detections). However, two Resource Monitoring Objectives, WSQ-1 and WSQ-2, require that water toxicity be monitored to support the determination that water quality does not exceed regulatory criteria and that ambient water toxicity be eliminated.

3.5.1 Data Use and Limitations

Monitoring toxic contaminants in the water column will provide information needed to assess the effectiveness of Galveston Bay Program Management actions. It will also support determinations of whether the following Resource Monitoring Objective:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediment by 2014

In addition to supporting these objectives, another purpose of monitoring toxic substances is to provide an assurance that there are no additions or changes in parameter concentrations that could induce new toxicity to the system.

The major limitation that exists is typically the analytical methods, particularly for the inorganic parameters. For example, many of the trace metals have specified regulatory criteria that are substantially lower than the minimum analytical level (MAL) of the most sensitive commercially available technique. In addition, working at very low ambient concentrations, it is frequently possible for false detections to occur from interference by a range of factors including sea salts. The result is that comparisons of this type have generated false detections in the past which resulted in considerable effort being expended. Later and better quality data have demonstrated that these concerns were misplaced, even with the very conservative numerical toxics criteria.

3.5.2 Sampling and Analytical Methods

There are several ongoing routine monitoring programs for toxic substances in the water column. These include the TNRCC, the US Army Corps of Engineers' Dredged Material Monitoring Program, and the EPA's EMAP and R-EMAP-TX programs. In addition, there have been a number of special studies conducted in the last several years which provide information on the concentrations of toxic parameters in the water column. The TNRCC procedures (TNRCC, 1993) involve selected stations and use of inductivity coupled plasma (ICP) spectroscopy methods for metals (6010 series) and 608/8080 methods for organics. The Corps monitors water from above areas to be dredged (as well as bulk sediment and elutriate concentrations) for metals and major pesticides and PAHs. The metals are analyzed using Graphite Furnace AA, and the organics using 8000 series EPA methods.

Recommended Methods

The methods recommended for trace metals and organic parameters differ substantially. Table 3-4 summarizes the acceptable methods for analysis of water samples.

In the case of the organic parameters, the EPA methods are the same that are currently being used by all monitoring programs. In that case, the selection criteria of comparability, cost, sensitivity, accuracy and precision all would favor the recommended method. For trace metal analyses the criteria of comparability is difficult to evaluate since the TNRCC, Corps and other federal efforts all use different analytical procedures. Furthermore, these procedures have evolved substantially over the last 10 years. There is no question that the cost criterion favors the TNRCC ICP methods. However, this is also the least accurate method and is of questionable value in marine waters. From the standpoint of sensitivity, accuracy and precision, the ultra-clean approach is a possible option.

Table 3-4. COMPARABLE AND ACCEPTABLE LABORATORY ANALYTICAL METHODS FOR TOXIC PARAMETERS

Parameter	EPA Method	Standard Methods
Dissolved metals	AA Furnace	3113 B ICP-MS
Mercury	245.1, 245.2	3500 Hg-B 245.5 (Sediment)
Volatile organics	624, 1624	6220 B
Acid-base neutral organics	625, 1625	6410 B, 6440
Pesticides	608, 625	6410 B, 6630 B,C

Alternative Methods

For trace metals, the so-called "ultra clean" procedures currently employed by Texas A&M University's Trace Element Research Laboratory and used in analyses for EMAP, NOAA NSTP and USFWS monitoring are a possible alternative method (GERG, 1990). The essential components of the ultra clean methods are to avoid sample contamination by carefully selecting and cleaning the collection equipment, sampling well away from the influence of a boat, and filtering either in the field or shortly thereafter with specially prepared equipment. With environmental contamination minimized the next major component of the work is extreme care in the use of laboratory equipment. If levels are below that which a spike can be accurately recovered from the water, any of several extraction techniques must be used to increase the concentration to the point where a reliable measurement can be made. A key component of this laboratory work is rigorous testing and cross-checking for contamination and instrument drift. The level of care must be unusually high in saltwater samples because of the presence of metals such as sodium and magnesium at levels many orders of magnitude greater than that of the trace metals being researched. However, although the collection techniques are straightforward, laboratory methods are more demanding than methods presently being used by participating laboratories.

3.5.3 QA/QC Considerations

Quality control specifications for water analyses have been incorporated into state law (*Texas Surface Water Quality Standards* Sections 319.1 - 319.12), as summarized in Table 3-2. Although designed to satisfy National Pollution Discharge Elimination System monitoring requirements, these specifications are considered appropriate for routine ambient water quality analyses. All laboratories conducting analyses for the Galveston Bay Program will follow these QA/QC procedures.

In addition, the Galveston Bay Program is planning to organize an annual workshop for agency personnel involved in sample collection activities. This workshop will provide training in standardized sample collection methods and provide an opportunity to disseminate updated methods as they become available.

CHAPTER 4
SEDIMENT QUALITY

Galveston Bay is the eventual repository for chemicals that are either discharged directly into the bay or delivered by rivers and streams that feed into the bay. Bay sediments represent the ultimate sink for many chemical toxics in the estuarine environment (USEPA, 1992). Bay sediments also represent an important habitat for many commercially, recreationally, and ecologically important organisms. A recent characterization report has documented declining trends in selected living resources (Loeffler and Walton, 1992). It is suspected that the introduction of anthropogenic contaminants into the Galveston Bay estuary is a major factor in the decline in species diversity and productivity that has been observed in areas of the estuary (Bechtel and Copeland, 1970; Copeland and Bechtel, 1971; Loeffler and Walton, 1992). However, ecological effects due to contaminants have been extremely difficult to distinguish from other human activities and natural variability (Luoma and Phillips, 1988; Loeffler and Walton, 1992). Sediment quality monitoring can provide information to evaluate potential stresses to estuary biota due to the presence of sediment contaminants, identify degrading benthic habitats, and track habitat recovery following environmental remediation actions.

A triad approach to sediment evaluation has been selected for the Galveston Bay Program. The sediment quality triad is intended to incorporate three essential types of data to define pollution degraded areas: measurements of (1) anthropogenic chemical contamination (i.e., bulk sediment chemistry), (2) toxicity to organisms (i.e., sediment bioassays), and (3) effects on resident infaunal communities (i.e., changes in infaunal community structure). It has been demonstrated that each data type alone is insufficient to demonstrate impacts to benthic communities due to sediment contamination (Chapman et al., 1987). Bulk sediment chemistry and physical measurements provide information on the amount and bioavailability of chemicals, but does not describe effects to communities. Bioassays provide information on sediment effects to selected laboratory organisms, but does not test field conditions of exposure by resident communities. Benthic community structure data provides information on effects to resident communities, but alone cannot relate changes in community structure to sediment contamination — alterations in community compositions may be due to sediment grain size, competition, predation, recruitment, salinity, and other factors. In addition, identification of pollution degraded areas based solely on alterations in community structure are usually difficult due to the high degree of variability in the structure of natural communities.

Sediment quality monitoring will provide information useful for evaluating the effectiveness of the following Galveston Bay Program Management Action:

- Reduce toxicity and contaminant concentrations in water and sediments.

A determination of whether the following Resource Management Objective is being attained will also be supported with this monitoring data:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014

This chapter describes methods for sampling and analyzing Galveston Bay sediments and the benthic infauna they support. The chapter is divided into the following monitoring topics:

Section 4.1	Sediment Collection
Section 4.2	Sediment Grain Size
Section 4.3	Benthic Infauna Identification and Enumeration
Section 4.4	Sediment Toxics
Section 4.5	Sediment Bioassays.

4.1 SEDIMENT COLLECTION

To mitigate the costs of field sampling and to permit valid correlation and multivariate analyses, it is recommended that sediment samples for chemical, toxicological, and benthic infauna analyses be collected simultaneously. Although sediments collected for sediment chemistry and toxicity analyses and sediments designated for benthic community analyses could be collected using different sampling devices, using one sediment sampling device simplifies sample collection activities.

4.1.1 Data Use and Limitations

Sediment samples are collected for grain size analysis, chemical analysis, benthic infauna investigations, or to be used in sediment bioassay testing. Data use and limitations vary according to the parameter collected for analysis and are discussed in detail in the following sections.

4.1.2 Sampling and Analytical Methods

A wide variety of sediment collection techniques are available. However, for the purposes of monitoring in Galveston bay to support the Resource Management Objective and action noted above, most collection activities will be concerned with only the top few centimeters of sediment. Many types of sediment dredges or grab samplers are available for sampling from vessels and by hand. For example, TNRCC use an Ekman dredge; the EMAP protocols call for a Young-modified van

Veen grab sampler; the US Army Corps of Engineers use sediment corers capable of penetrating the sediment to proposed construction depths because of the regulatory requirement to test the entire sediment column; NOAA specifies a Smith-McIntyre grab, a box corer, or a van Veen grab, depending on the program (Benthic Surveillance or Mussel Watch); and the USFWS use a 10-cm (4-inch) diameter corer to sample to depths of 7.5-10 cm.

Recommended Methods

It is recommended that sediment samples for different types of analyses be collected simultaneously and that one type of sampling device be used for monitoring purposes. An Ekman dredge, as used by TNRCC is the recommended device. This dredge is versatile, can penetrate and collect sufficient volume of sediment for nearly all requirements (except for proposed dredging material), and it is relatively simple to operate correctly.

For each sampling event, the sample should be evaluated to determine whether the following sample acceptability criteria are met:

- Sampler is not over-filled with sample so that the sediment is pressed against the top of the sampler
- Overlying water is present, indicating minimal leakage
- Overlying water is not excessively turbid indicating minimal sample disturbance
- Sediment surface is relatively flat and level with the sampler indicating minimal disturbance or winnowing
- Desired penetration depth is achieved — at a minimum, the aerobic layer should be sampled because this zone is where most of the benthic infauna live and includes the most recent sediment deposition (Day et al., 1989; USEPA, 1992; Loeffler and Walton, 1992).

If the sample does not meet these criteria, resampling is required. If the sample meets these criteria, gently decant all the overlying water, taking care not to remove surficial sediments.

The aerobic layer of bottom sediments can usually be identified based on color (TWC, 1993) and homogenized to assess average infaunal exposure to sediment contaminants. The depth of the aerobic layer will be recorded in the field notebook. If the aerobic layer is less than 2 centimeters, as it can be in portions of the upper Houston Ship Channel during the summer, the upper 2 centimeter will be collected and homogenized.

Once the sample is transferred from the dredge to a sample container, seal and label the container with the station identification code, date, and type of analyses requested (e.g., metals analysis). For each sample, the following information should be recorded in the field notebook:

- Sample identification code
- Name of collector
- Location
- Date
- Time
- Habitat
- Water depth
- Weather conditions
- Number of grabs composited

- Sample description
  - color
  - odor
  - presence of sheen
  - consistency/texture
  - gross grain size
  - obvious organisms or plants, and unusual objects

At a minimum, 300 mL of sediment is required; 500-800 mL of sediment is preferred. Recovering sufficient sample volume usually will not present a problem because of the capacity of the sampler. A portion of the sample will undergo sediment chemistry analyses; the other portion will be used to conduct sediment toxicity tests.

A minimum of three replicate samples are recommended to be collected at each station and composited to form the final sample. Separate samples will be collected for benthic community assessment. Analysis of historical data indicate that a minimum of four replicate Ekman grabs should be used for benthic community assessment (G. Guillen, TNRCC, personal communication).

More detailed information on sampling procedures can be found in:

Water Quality Monitoring Procedures Manual. Draft. TNRCC (TWC), 1993.

4.1.3 QA/QC Considerations

When collecting sediment samples for chemical analyses or toxicity tests, avoid airborne (e.g., engine exhaust, cigarette smoke) and other sources of contamination. All sampling equipment (e.g., siphon hoses, scoops, containers) must be made of noncontaminating material and cleaned prior to use. Wear clean gloves when touching samples or sampling containers. Standard clean techniques are used to store, transfer, and process sediments. All samples are stored in clean USEPA approved containers and placed in the dark at less than 4° C until delivery to the laboratory. More detailed QA/QC considerations are discussed in the following sections.

4.2 SEDIMENT GRAIN SIZE

Grain size is used to characterize the physical characteristics of estuarine sediments. The availability of sediment contaminants and organic content are often correlated with sediment grain size. Because grain size influences chemical variables, it can be used to normalize chemical concentrations. Accordingly, grain size is an essential element of sediment sampling and analysis.

4.2.1 Data Use and Limitations

Grain size data often explain the temporal and spatial variability in biological assemblages; changes in sediment grain size often affect an infaunal organism's ability to build tubes, capture food, and escape predation. Grain size can be used to account for some of the variation found in biological assemblages.

Grain size data may be used to:

- Monitor rates of recovery following environmental interventions
- Evaluate the condition of benthic habitats
- Assist in providing early warnings of potential impacts to the estuarine ecosystem.

Sediment grain size composition is often temporally stable, although some slight seasonal variability may be present. Changes are usually associated with seasonal patterns of benthic turbulent mixing and sediment transport phenomena. The frequency of sampling should be related to the expected rate of change in grain size composition. A consistent sampling period is recommended in order that spatial and temporal comparisons may be conducted.

4.2.2 Sampling and Analytical Methods

Recommended Methods

Recommended sampling techniques are discussed in Section 4.1 (Sediment Collection). If seasonal variations are exhibited, it is recommended that direct comparisons between samples collected during different seasons be avoided. Studies investigating interannual variation in the grain size composition should conduct sampling during the same season (preferably the same month) each year.

Sediment grain size may be expressed in either millimeter (mm) or j (phi) units. These scales are related according to the equation:

$$j = -\log_2 (mm)$$

Data should be converted to phi units before calculation of grain size parameters. Sediments are broadly classified into three size classes: silts and clays are less than 0.064 mm (4 j) in diameter, sands range from 0.064 mm (4 j) to 1 mm (0 j) in diameter, and gravels are larger than 1 mm. Grain size is normally reported as the mean, although the median grain size is sometimes used. Sorting is a measure of the spread of the grain size distribution.

NOAA's *Sampling and Analytical Methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984-1992* (NOAA, 1993) NOS ORCA 71 and
EMAP Estuaries Laboratory Methods Manual. (USEPA, 1993) EPA/600/4-91/024, provide a review of the methodological and statistical analysis of sediment grain size.

Particle size determination can either include or exclude organic material. If organic material is removed prior to analysis, the "true" particle size distribution is determined. If organic material is included in the analysis, the "apparent" particle size distribution is ascertained. Most organic material is in the silt/clay size range and can be removed from the sediment either by acid washing or ashing. If organic material is left in the sediments, it will tend to bias the results toward a smaller mean size. Because true and apparent distributions differ, detailed comparisons between samples analyzed by these different methods are questionable. It is therefore recommended that measures of sediment grain size be examined using only one of these methods. A standardized grain size analysis will allow all comparisons between samples.

Particle-size analysis of a sediment sample will often require the use of two or more methods because of the wide range of particle sizes encountered. Sieves are recommended for separation of the coarser fractions, electronic particle counters or pipette methods for the finer particle fractions. Detailed instructions for both methods are presented in Plumb (1981) and PSEP (1986).

4.2.3 QA/QC Protocols

It is recommended that triplicate analyses be conducted on one of every 20 samples, or on one sample per batch if less than 20 samples are analyzed. It is also recommended that the analytical balance, drying oven, and temperature bath be inspected daily and calibrated at least once per week. More detailed QA/QC procedures are outlined in the two references cited above and in Plumb (1981) and PSEP (1986).

4.3 BENTHIC INFAUNA SAMPLING

Benthic infauna are important mediators of nutrient cycling and important prey for species at higher trophic levels — especially for large epibenthic invertebrates and fish, many of which are of recreational or commercial importance. Benthic infauna are also exceptional indicators of benthic conditions because they:

- Are generally sedentary — observed effects are in response to local environmental conditions

- Are sensitive to habitat disturbance — communities undergo dramatic changes in species composition and abundance in response to environmental perturbations

- Often mediate the transfer of energy and toxic substances in the ecosystem — via bioturbation and as important prey organisms

Benthic infauna monitoring will provide information to support a determination of whether the following Resource Management Objectives are being attained:

HP-5: Restore natural functions and values to 50 percent of degraded wetlands within 20 years

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014.

Monitoring of the benthic community will also support evaluation of progress towards the Species Population Protection Management Goal:

- Reverse the declining population trend for affected species of marine organisms, and maintain the populations of other economic and ecologically important species.

4.3.1 Data Use and Limitations

Benthic infauna community data can provide *in situ* measures of sediment quality and biotic condition. In addition to assessing sediment quality, the collection of benthic infauna data serves a number of uses, including assessing wetland quality and determining the condition of estuary biota.

Recommended measurements of community structure include:

- Biomass
- Number of individuals
- Number of species
- Species dominance
- Abundance of contaminant-sensitive species
- Abundance of opportunistic and contaminant-tolerant species.

Typically, areas of severely degraded sediment quality are characterized by low numbers of individuals and species. Highly degraded areas are dominated by a few, highly-abundant populations of small-bodied opportunistic or contaminant-tolerant species. Areas of superior sediment quality are characterized by many small populations of competitively dominant species (Pearson and Rosenberg, 1978). These measures of community structure have proved useful over various habitats and regions (USEPA, 1992).

4.3.2 Sampling and Analytical Methods

Directly relating changes in benthic communities to levels of sediment-adsorbed contaminants has been difficult because infauna appear to be highly sensitive to a number of dynamic physical and chemical factors. Of significant importance is their sensitivity to changes in grain size — some benthic organisms appear to be more sensitive to changes in sediment grain size than to concentrations of sediment-adsorbed contaminants (Long et al., 1990). To accurately explain changes in the distributions or loss of specific benthic organisms, measurements of grain size in conjunction with concentrations of sediment contaminants must be collected.

Infaunal sampling is normally performed with either an Ekman dredge, Surber sampler, or kicknet, depending on the water depth and substrate type. Although, other types of grabs have been used for sediment sampling (see section 4.1.2), an Ekman dredge, as used by TNRCC, is recommended for both sediment collection and benthic sampling.

Recommended Methods

Collection Procedures: For consistency in sampling through the Ekman dredge is recommended as the preferred sampling mechanism. Field procedures for the Ekman dredge are described in Section 4.1.

Wash sediments overboard through a sieve bucket, mesh size 0.5 mm, by dunking the bucket gently. Wash material retained on bucket screen onto a wide-mouthed container. Check the screen for organisms trapped in or wound around the mesh wires and back-wash the screen into the container with a high pressure spray to dislodge any sediment grains that may be caught in the mesh. Add relaxant (7 percent Mg_2Cl in sea water) to a depth of 3 cm, completely covering the sample (narcotization of the sample will aid in the subsequent identification of soft-bodied species).

After the sample has been narcotized for at least 0.5 to 1 hour, add a 10 percent borax-buffered formalin solution to the sample container — samples containing large amounts of fine grained sediments, peat, or wood plant material may require higher concentrations. The volume of the fixative should be at least twice the volume of the sample. Rose-bengal can be added to the formalin solution to assist in separating organisms from sediment in the laboratory. Add the fixative solution until the container is completely filled to minimize abrasion during shipping and handling. Label the sample bottle with the name of the collector, station number, date, time, number of dredges composited, depth of collection, and preservative used. Store samples in the dark at moderate temperatures. After being stored for approximately 1 hour, samples should be inverted several times to ensure adequate mixing.

The following information should be recorded in the field notebook at the time of sampling:

- Sample identification code

- Name of collector
- Location
- Date
- Time
- Habitat
- Water depth
- Weather conditions
- Type of sampler used
- Preservative used
- Sample description
    - area and volume of sample
    - effort and duration of the sampling effort
    - color
    - odor
    - presence of sheen
    - consistency/texture
    - gross grain size
    - obvious organisms or plants, and unusual objects.

This procedure is described in more detail in *Water Quality Monitoring Procedures Manual. Draft.* TWC, 1993.

Laboratory Procedures: Sort, identify, and enumerate organisms found in the sample in the laboratory within two weeks, and preserve in 70 percent ethyl alcohol solution. Samples should remain in the formalin-seawater solution for a minimum of 24 hours to allow proper fixation; a maximum fixation period of 7 to 10 days is recommended to reduce the risk of decalcifying molluscs and echinoderms. After fixation, wash samples on a sieve with mesh openings half the size (at most) of those used in the field. For long-term storage of crustaceans, substitute glycerine for some of the water (70 percent ethyl alcohol, 25 percent water, 5 percent glycerine). Glycerine keeps the exoskeleton supple, facilitating examination and manipulation.

Gently flush the sample with large quantities of fresh water, being careful not to splash any sample material. Allow rinse water to completely drain from the sieve and lightly rinse the sample with a 70 percent ethyl alcohol solution. Wash sample into a sample jar filling it no more than three quarters full. Rinse the last bit of material into the jar using a squirt bottle. Fill the jar with 70 percent ethyl alcohol. Gently shake and invert jar to ensure mixing.

Using a 10x power dissection scope, systematically sort the sample by removing each organism and placing it into a petri dish. Care must be taken that enough liquid is present in the petri dish to completely cover the sample. Sort each petri dish twice to ensure that all organisms are removed. Using an analytical balance, measure biomass by taking the difference between a beaker filled with preservative before and after organisms are placed in the beaker. Do not blot organisms prior to weighing. This technique appears to introduce the least amount of variation into the weighing process.

After biomass estimates are completed, identify and count organisms. Unless otherwise specified, identifications should be to the lowest practical taxonomic unit. Generally, it is necessary to only speciate the dominant organisms. If possible, at least two references should be used for each species identification. Moreover, each species identification should be checked against a reference specimen from a verified reference collection. After completing taxonomic identification, place all organisms in vials containing 70 percent ethyl alcohol solution. Label each vial (see reporting information given above). Store all vials for a single sample in common jars and immersed in 70 percent ethyl alcohol solution.

Each taxonomist should initial identifications and counts in a notebook which also include notes and comments on the organisms in each sample. Have the taxonomists sign and date sample data sheets.

4.3.3 QA/QC Protocols

Sample Analysis: It is recommended that at least 20 percent of each sample be re-sorted for QA/QC purposes. Re-sorting is the examination of a sample that has been sorted once and is considered free of organisms. Re-sorting should be conducted by an individual other than the one who sorted the original sample. To ensure that identifications are correct, 5 percent of all samples identified by one taxonomist should be re-identified by another taxonomist.

Send at least three individuals of each taxon to recognized experts for verification. Place the verified specimens in a permanent reference collection. Label all specimens in the reference collection and segregate by species and sample. Archive reference specimens alphabetically within major taxonomic groups. Have the laboratory staff participate in a regional taxonomic standardization program (if available) to ensure regional consistency and accuracy of identifications.

At a minimum, calibrate the analytical balances used for biomass determinations weekly. Service all balances and microscopes at regular intervals. Annual service and inspection is adequate in most cases, unless the manufacturer recommends otherwise.

4.4 SEDIMENT TOXICS

The parameters of primary concern in sediments include the full range of organic substances designed to control undesirable organisms (e.g., insecticides, fungicides, etc.), a range of organic substances that were not intended to be toxic as a product but which have toxic effects (e.g., PCBs, dioxin, tributyltin, etc.), a wide range of organic compounds associated with development (e.g., polycyclic aromatic hydrocarbons, etc.) and trace metals. All of these are particle-adsorbing to some degree, making them tend to be concentrated in areas of recent sediment deposition. As a result of being concentrated, it is much easier to detect the substances in the sediment. For that reason, most efforts at toxics monitoring are focused on sediment analyses, with enough water analyses to provide an accurate documentation of levels and to assure the absence of a problem.

Sediment monitoring is routinely performed in Galveston Bay by both the TNRCC and by the Corps of Engineers. In addition, a wide range of special studies of sediment characteristics are conducted by several federal agencies (NOAA Status and Trends; USEPA EMAP). The TNRCC monitors a wide range of stations while the Corps concentrates on sediments in navigation channels that are proposed for dredging.

The list of chemicals of concern for the Galveston Bay Program is based on those selected by the USEPA EMAP program (Table 4-1). This will provide a comparison of results against the EMAP data for consistency and will provide some additional data for the evaluation of Resource Management Goals.

4.4.1 Data Use and Limitations

The collection of bulk sediment chemical data will be used to support the evaluation of the following Resource Management Objective:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014,

and the effectiveness of associated Galveston Bay Plan Management Actions:

- Reduce contaminant concentrations to meet standards and criteria
- Determine sources of ambient toxicity in water and sediment.

Parameters for the measurement of sediment toxicity have been selected to determine the effectiveness of actions related to the Resource Management Objective. Information on concentration levels is needed to assess the trends in toxicity and the possible effect of elevated concentrations on the living resources within Galveston Bay. Determinations of sediment contaminant levels, along with bioassay testing and benthic community evaluations will provide information needed to assess the effects on living resources.

The primary limitation is that while a wide range of substances which are potentially toxic tend to adsorb to particles and accumulate in the sediment, the actual biological effect of such materials is highly variable due to the chemical form of materials in the sediment and the effect of natural complexing agents. The net effect is that it is quite difficult to define relationships between toxic concentrations in sediments and biological effects. Alternatives, including bioassay testing for particular purposes such as dredged material disposal, and benthic assessments of ambient sediments, are discussed under Alternative Methods.

Table 4-1. SEDIMENT CONTAMINANTS OF CONCERN FOR THE GALVESTON BAY PROGRAM

PAHs

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Biphenyl
Chrysene
C1, C2, C3, C4 Chrysene
Dibenzo(a,h)anthracene
Dibenzothio
C1, C2, C3-dibenzothio
Fluoranthene
C1-fluoranthpyrene
Fluorene
C1, C2, C3-fluorene
Naphthalene
C1, C2, C3, C4-naphthalene
Perylene
Phenanthrene
C1, C2, C3, C4-phenanthrene
Pyrene
1,2,3-c,d-pyrene
1-methylnaphthalene
2-methylnaphthalene
2,3,5-Trimethylnaphthalene
2,6-Dinethylnaphthalene
1-methyulphenanthrene
High Molecular Wt. PAH's
Low Molecular Wt. PAH's
Total PAH's

PCBs

Pesticides

2,4'DDD
4,4'DDD
2,4'DDE
4,4'DDE
2,4'DDT
4,4'DDT
Aldrin
alpha-BHC
beta-BHC
delta-BHC
alpha-chlordane
gamma-chlordane
Dieldrin
Endrin
Heptachlor
Heptachlor epoxide
Methoxychlor
Lindane
Toxaphene
Malthion
Parathion
Diazinon
Endosulfan
Mirex
Total BHCs

Inorganics

Aluminum
Antimony
Arsenic
Cadimum
Chromium
Copper
Iron
Lead
Manganese
Mercury
Nickel
Selenium
Silver
Tin
Zinc
Tri-butyl tin

4.4.2 Sampling and Analytical Methods

Monitoring of selected parameters in sediments is required under the Galveston Bay Plan and will be performed. However, because part of the reason that sediment chemical (toxics) monitoring is conducted is to try to explain some observed degradation of a sediment, it is recommended that sediments be examined concurrently for the health and diversity of the benthic community and for toxicity effects on appropriate indicator species.

Recommended Methods

Table 4-2 provides a list of analytical techniques for metals and organic compounds and the respective EPA Method numbers. Methods for sediment analyses are

Table 4-2. LIST OF EXISTING ANALYTICAL TECHNIQUES (U.S. EPA, 1986a)

Metals/Metalloids

• Atomic Absorption
Spectrophotometry (AAS) USEPA Method 7000 series
- flame
- graphite furnace (GFAA)
- cold vapor USEPA
Method 7470
- gaseous hydride
(HYDAAS) USEPA Methods 7060 and 7740

• Inductively Coupled Plasma
Emission USEPA Method 6010
Spectrometry (ICP)

Organics

• Gas Chromatography (GC)
- with electron capture
detection (GC/ECD) USEPA Method 8080
- with mass spectrometry
(GC/MS) USEPA Methods 8240 and 8270

ICP – Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, Se, Sn, Ag, Na, Tl, V, and Zn
AAS – Al, Sb, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, Ag, Na, Tl, Sn, V, and Zn

generally based on those described by Plumb (1981). Variations and improvements are being developed continuously and can be found in more recent publications. As an overall guide, it is recommended that the latest EPA method or equivalent acceptable method be used. Either USEPA regional laboratories, or other laboratories working within the USEPA Contract Laboratory Program are recommended to perform the required analyses for routine monitoring.

Dissolved Metals: Sample collection methods have been discussed in Section 4.1. Appropriate sample handling methods require that samples be frozen and kept at -20°C (USEPA, 1987). Although specific holding times have not been recommended by USEPA, a maximum of 6 months (8 days for mercury, ASTM, 1991) would be consistent with holding times for water samples. A summary table for holding times, container types, and preservation methods is given in Table 4-3.

Selection of analytical methods is based on a trade-off between full-scan analyses, which are economical but cannot provide sufficient sensitivity for some compounds, and alternate methods that are more sensitive for specific compounds but can require greater analytical costs.

For sample preparation, the USEPA Contract Laboratory Program (CLP) requires the use of $HNO_3.H_2O_2$ for metal digestion (USEPA, 1991c). Because dissolved metals are the focus of the monitoring, and not total metals, more complete digestion procedures are not required. A combination of atomic absorption spectrophotometry (AAS) and inductively coupled plasma (ICP) emission spectroscopy is proposed for the detection and quantification of trace metals. Analyses for aluminum, chromium, copper, nickel, silver, and zinc will be conducted using ICP emission spectroscopy. Analyses for arsenic, cadmium, lead, and selenium will be conducted using graphite furnace atomic absorption spectrophotometry (GFAAS). Mercury will be analyzed using cold vapor AAS (USEPA, 1986a).

Acid Volatile Sulfides (AVS) concentration has been shown to be a useful tool for predicting bioavailability of metals in anoxic sediments. While the focus of sediment sampling is in the aerobic zone, AVS analyses are recommended to extend the assessment of sediment quality. Analysis of (AVS) is recommended to be conducted in accordance with draft EPA method (USEPA, 1991c) using GFAAS. Total Organic Carbon (TOC) will be measured using a Coulometer TOC analyzer. Both of these parameters are recommended to be used to normalize metallic and organic contaminants, respectively.

Semi-Volatile Organic Compounds: The isotope dilution technique, which requires spiking the sample with a mixture of stable isotope labeled analogs of the analytes, is proposed because reliable recovery corrections can be made for each analyte with a labeled analog or a chemically similar analog (USEPA, 1986a). Holding times, container types, and preservation methods for organic compounds can be found in Table 4-3.

Table 4-3. SAMPLING CONTAINERS, PRESERVATION REQUIREMENTS, AND HOLDING TIMES FOR SEDIMENT SAMPLES

Contaminant	Container[a]	Preservation	Holding Time
Metals			
Chromium VI	P, G	Cool, 4°C	40 hours
Mercury	P, G		8 days
Metals, except above	P, G		6 months
Organic Compounds			
Extractables (including phthalates, nitrosamines, organochlorine pesticides, PCBs, nitroaromatics, isophorone, polynuclear aromatic hydrocarbons, haloethers, chlorinated hydrocarbons and TCDD)	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)
Extractables (phenols)	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)
Purgeables (halocarbons and aromatics)	G, teflon-lined septum	Cool, 4°C	14 days
Purgeables (acrolein and acrylonitrile)	G, teflon-lined septum	Cool, 4°C	3 days
Pesticides	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)
Chlorinated organic compounds	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)

[a] Polyethylene (P) or Glass (G)
SOURCE: American Society for Testing and Materials, 1991

A combination of capillary gas chromatography with electron capture detection (CGC/ECD), gas chromatography with mass spectrometry (GC/MS), and compound-specific analyses is proposed for the detection and quantification of semi-volatile organic compounds (USEPA, 1986a). Analysis of pesticides will be conducted using CGC/ECD. CGC/ECD provides greater sensitivity relative to using GC/MS, however CGC/ECD does not provide positive compound identification. Confirmation of pesticides by GC/MS, when sufficient concentrations occur, is recommended. PCB congener-specific analyses are recommended because they provide more accurate identification and quantification of PCBs and eliminate the necessity of subjective decisions on the part of the analyst. Analysis of all other semi-volatile compounds will be conducted using GC/MS. These methods and the equivalent EPA Method numbers are summarized in Table 4-2.

Volatile Organic Compounds: Analyses of volatile organic compounds will be conducted using purge and trap CGC/ECD techniques (USEPA, 1986a). When sufficient concentrations occur, GC/MS is recommended. These methods and the equivalent EPA Method numbers are summarized in Table 4-2.

Detection Limits: Accurate measurement of bioavailable concentrations are required to evaluate hazards due to bioaccumulation of sediment contaminants. Over 80% of the available measurements of sediment organics are below detection limits. Selection of more sensitive state-of-the-art analytical methods should be considered for those parameters where there are toxicological data indicating the potential for effects at concentrations lower than obtained with routine methods. On the other hand, if there is no indication of adverse effects at present detection levels, there is no reason to reduce the detection limits.

Alternative Methods

AVS analyses, mentioned above, are recommended to be included in the routine suite of parameters to be monitored. Continuing developments in metal and organic analyses, especially in a saltwater matrix, should be tracked and considered for inclusion in the overall analytical program. This is especially true of methods that provide more robust analyses with lower detection limits.

4.4.3 QA/QC Considerations

Appropriate QA/QC procedures for collection and analysis can be found in several documents, including specific QA/QC guidance documents and also within the analytical methods documents. Each analytical laboratory should, as part of its overall QA/QC program, follow prescribed QA/QC procedures for each type of analysis performed. Some appropriate QA/QC references are:

> *Guidance for Sampling of and Analyzing for Organic Contaminants in Sediments.* U.S. Environmental Protection Agency, 1987. EPA 440/4-87-010.
>
> *Methods for the Determination of Metals in Environmental Samples.* U.S. Environmental Protection Agency, 1991. EPA 600-4-91-010.
>
> *Sampling and Analytical Methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984-1992.* NOAA, 1993. NOS ORCA 71.
>
> *EMAP-Estuaries Louisianian Province: Quality Assurance Project Plan for 1993.* U.S. Environmental Protection Agency (Heitmuller and Valente, 1993). EPA/600/X-93/XXX.

For analyses of metals, samples should be frozen and kept at -20°C (USEPA, 1987). Although specific holding times have not been recommended by USEPA, a maximum of 6 months (8 days for mercury; ASTM, 1991) would be consistent with holding times for water samples (Table 4-3).

For analyses of volatile compounds, samples should be stored in the dark at 4° C. Analyses of volatile compounds should be performed within 14 days of collection (USEPA, 1987). If analyses of semivolatile compounds will not be performed within the recommended 7-day holding time, freezing of the samples at -20° C is advised. Holding times for frozen samples has not been established by EPA (Table 4-3).

Samples for determination of TOC and AVS should be analyzed as soon as possible. If not analyzed immediately, TOC samples should be refrigerated and their pH brought below 2 by addition of phosphoric acid. Acidification is recommended only when inorganic carbon is below detection limits (APHA, 1992). AVS samples should be stored in airtight containers under an inert atmosphere and analyzed as soon as possible.

Field QA/QC Checks

Travel blanks can indicate whether contamination was introduced by reagents in the field or introduced during shipping of samples. Rinsate blanks are designed to verify the absence of contamination that can be carried over from one sample to another due to inadequate cleaning of field equipment. Field splits, treated and identified as separate samples, may be sent to the same laboratory for analysis or one sample may be sent to a "reference" laboratory for comparison. Standard reference material should be placed in a sample container at the time of collection and sent "blind" to the laboratory. Every 20th sample should be employed as a field blank.

Instrument QA/QC Checks

Calibration standards should be analyzed at the beginning of sample analysis, and should be verified at the end of each 12-hour shift during which analyses are performed (USEPA, 1987). The concentration of calibration standards should bracket the expected sample concentrations, otherwise sample dilutions or sample handling modifications (i.e., reduced sample size) will be required.

Method QA/QC Checks

Tables 4-4 and 4-5 provide a summary of sample/replicate/blank QA/QC procedures for laboratory analyses. Analysis of method blanks should be conducted to demonstrate the absence of contamination from sampling or sample handling in the laboratory. At least one method blank must be included with each batch of samples and should constitute at least five percent of all samples analyzed.

Table 4-4. SUMMARY OF QUALITY CONTROL SAMPLE

Sample Type	Recommended Frequency of Analysis
Surrogate spikes	Required in every sample - minimum 3 neutral, 2 acid spikes, plus 1 spike for pesticide/PCB analyses, and 3 spikes for volatiles. Isotope dilution techniques (i.e., with all available labeled surrogates) is recommended for full scan analyses and to enable recovery corrections to be applied to data.
Method blank	One per extraction batch (semivolatile organics). One per extraction or one per 12-hour shift, which ever is most frequent (volatile organics).
Standard reference materials	<50 samples: one per set of samples submitted to lab. >50 samples: one per 50 samples analyzed.
Matrix spikes	<u>Not</u> required if complete isotope dilution technique used. <20 samples: one per set of samples submitted to lab. ≥20 samples: 5 percent of total number of samples.
Spiked method blanks	As many as required to establish confidence in method before analysis of samples (i.e., when using a method for the first time or after any method modification).
Analytical replicates	<20 samples: one per set of samples submitted to lab ≥20 samples: one triplicate and additional duplicates for a minimum of 5 percent total replication.
Field replicates	At the discretion of the project coordinator.

Spike recovery analyses are recommended to assess method performance for the particular sample matrix. Spike recoveries serve as an indication of analytical accuracy, whereas analysis of standard reference materials (SRM) measure extraction efficiency. Recommended control limits include 75 to 125 percent recovery for spikes and 80 to 120 percent recovery for SRM.

Replicates are recommended to assess the precision of laboratory analyses. A minimum of five percent of the analyses should be laboratory replicates. The acceptable variation among replicates is 20 percent or less.

Table 4-5. SUMMARY OF WARNING AND CONTROL LIMITS FOR QUALITY CONTROL SAMPLE

Sample Type	Recommended Warning Limit	Recommended Control Limit
Surrogate Spikes	10 percent recovery	50 percent recovery
Method Blank Phthalate, Acetone	30 percent of the analyte of the analyte	5 µg total or 50 percent
Other Organic Compounds	1 µg total or 5 percent of the analyte of the	2.5 µg total or 5 percent of the analyte
Standard Reference Materials	95 percent confidence interval	95 percent confidence interval for Certified Reference Material
Matrix spikes	50-65 percent recovery	50 percent recovery
Spiked Method Blanks	50-65 percent recovery	50 percent recovery
Analytical Replicates	– coefficient of variation	±100 percent
Field Replicates	–	–
Ongoing Calibration		25 percent of initial calibration

4.5 SEDIMENT BIOASSAYS

Toxicity monitoring supports the evaluation of attaining the Resource Management Objective:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014.

The purpose of bioassay testing is to detect any adverse effect on aquatic organisms that might not otherwise be identified from direct chemical measurements or to correlate contaminant concentrations with acute or chronic observable biological effects. For example, bioassays are widely used in monitoring of permitted effluents to detect toxic effects that would not be shown in routine chemical monitoring.

4.5.1 Data Use and Limitations

Toxicity of bay sediments will be evaluated using sediment elutriate tests adopted from USEPA acute toxicity methods. Both a vertebrate and invertebrate species will be evaluated for responses to exposure to bay sediments. Marine tests are the 9-day embryo-larval and tetrogenicity chronic test for Inland Silversides *(Menidia beryllina)* and the 96-hour acute test for mysids *(Mysidopis bahia)*. These test species are included in the USEPA list of recommended acute toxicity test organisms (USEPA, 1991d). They are easily cultured in the laboratory, are sensitive to a variety of pollutants, and are generally available throughout the year from commercial sources. These tests, conducted by the USEPA Region 6 laboratory for the TNRCC, have been shown to provide valuable information on bay-area sediment quality.

Sediment elutriate testing, as opposed to whole sediment testing, was chosen because the Galveston Bay system is a shallow estuary in which the waters are frequently subject to moderate wind conditions, resulting in significant sediment resuspension. This method is used in support of the National Pollutant Discharge Elimination System permitting program within USEPA Region 6. It is planned that the method and test species will be evaluated over a two-year period to determine the value of the results. The procedures and test species are subject to modification after this time to improve the monitoring program and the assessment of progress toward the Resource Management Objective and associated action plans.

4.5.2 Sampling and Analytical Methods

Recommended Methods

The recommended method is identical to that developed by the USEPA Region 6 laboratory in Houston, and is adapted from USEPA (1988) and USEPA and USACE (1991). Sediment elutriates are prepared by combining a sub-sample from the homogenized sediment sample with the appropriate culture water ratio of 1:4 on a volume basis. After the correct ratio is achieved, the mixture is tumbled end-over-end for approximately 24 hours, after which time the mixture is allowed to settle for an additional 24 hours at 3-4°C. After settling, the supernatant is siphoned off without disturbing the settled material. If fine particulate matter is present and would prohibit the observation of the test organisms, the elutriate is then passed through a 1.5 micron glass fiber filter before testing is initiated.

Laboratory culturing, holding, and handling protocols for the test organisms are described in:

> *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. 4th ed.* USEPA, 1991.

Laboratory procedures for acute toxicity testing and subsequent data analysis are also addressed in the same document.

Alternative Methods

Because these procedures and test species are under evaluation as to their utility for the Galveston Bay Regional Monitoring Program for the next two years, no changes are recommended. Once sufficient results from the bioassay testing have been accumulated, an analysis of those results may provide indications as to how the methods or species may be improved.

4.5.3 QA/QC Considerations

Quality assurance protocols applicable to facilities and equipment, test organisms, elutriate sampling and handling, and acceptability of acute toxicity test results are discussed in detail in the procedures document cited above (USEPA, 1988).

CHAPTER 5
HABITAT DISTRIBUTION AND CONDITION

Monitoring habitat distribution and condition in and around the Galveston Bay estuary will provide data necessary to directly or indirectly assess attainment of the following Resource Management Objectives:

HP-3: Sustain no net loss of wetland areas.
HP-4: Create or restore 15,000 acres of vegetated wetlands within 10 years.
HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.

This Chapter is divided into two sections. Section 5.1 (Areal Extent, Distribution, and Classification) addresses methods that are used to monitor changes in the amount and distribution of habitats. Section 5.2 (Habitat Function and Value) describes methods that are used to evaluate the condition of habitats based on their suitability for serving various ecological functions and values assigned them.

The Habitat Protection Task Force identified freshwater marsh, emergent estuarine marsh, and submerged aquatic vegetation (SAV) as candidate indicators of habitat distribution and condition in Galveston Bay.

5.1 AREAL EXTENT, DISTRIBUTION, AND CLASSIFICATION

The Galveston Bay estuary is composed of a variety of habitat types which support a diverse group of plant and animal species. The continued health and productivity of the Estuary depends on maintaining these diverse, high-quality habitats. Ensuring the protection of habitats in the Galveston Bay estuary is a major concern of the Galveston Bay National Estuary Program.

5.1.1 Data Use and Limitations

Monitoring the areal extent and distribution of selected habitats provides information that directly supports a determination of whether the following Resource Management Objectives are being met:

HP-3: Sustain no net loss of wetland areas.
HP-4: Create or restore 15,000 acres of vegetated wetlands within 10 years.

The methods used to classify Galveston Bay habitats and monitor their areal extent must be capable of differentiating various wetland types and quantifying their extent with an acceptable level of accuracy. To ensure that valid comparisons can be made with existing data, the classification system used should also be comparable with previously identified wetland types in Galveston Bay and be consistent with that used in monitoring wetland function and value (Section 5.2). This will allow net changes in wetland function and value to be estimated on an estuary-wide basis.

Agency Mandates/Objectives

In 1991 the TNRCC defined wetlands and included them as waters of the state thus providing these areas protection under the Texas Surface Water Quality Standards (TNRCC, 1994). The TNRCC identifies six wetland categories in the Standards: Tidal Wetlands, Brackish Wetlands, Isolated Wetlands, Playa Lakes, Riparian Wetlands, and Forested Wetlands. The following revisions to the standards proposed in the 1994 triennial review (TNRCC, 1994) also are relevant to regional monitoring of wetland aerial extent and distribution:

- Site-specific assessment of uses and standards in response to any TNRCC permitting action

- Numerical criteria to protect aquatic life from acute toxicity and additional numerical toxic criteria where appropriate.

TNRCC (1994) states that the wetland standards are particularly pertinent to:

- State reviews of U.S. Army Corps of Engineers permits for dredge and fill operations

- Delegation and implementation of the Texas Coastal Zone Management Program.

5.1.2 Sampling and Analytical Methods

This subsection begins with a brief description of sampling and analytical methods that have been used to measure the areal extent and distribution of habitats in Galveston Bay. The Regional Monitoring Steering Committee has selected a monitoring approach from among these alternatives for use in the Galveston Bay Regional Monitoring Program.

Existing Monitoring Programs

The U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) and the National Oceanic and Atmospheric Administration (NOAA) Coast Watch

Change Analysis Program (C-CAP) measure the extent and distribution of habitats in Galveston Bay. In addition, GBNEP has sponsored research directed at mapping the extent and distribution of various wetland types in Galveston Bay, based on NWI data. Although several investigators have measured the extent and distribution of SAV in Galveston Bay, there is no routine monitoring of this habitat in the estuary.

The USFWS NWI is establishing a database on the extent and characteristics of wetlands in the United States based on aerial photographs. Under this program wetlands are mapped on 7.5 - or 15 - minute U.S. Geological Survey topographic maps and classified according to the USFWS Classification of Wetlands and Deepwater Habitats of the United States (Cowardin, et al., 1979; USFWS, 1990). Photo interpretation, cartographic, and digitizing conventions have been adopted by the USFWS to ensure consistency and aid workers in photo interpretation and mapping (USFWS, 1990; USFWS, 1994a; USFWS, 1994b).

Eventually the entire USFWS NWI system will be computerized into digital geographic information systems (GIS) to provide continuous, detailed monitoring of the extent of wetlands described according to the Cowardin et al. (1979) system (Mitsch and Gosselink, 1993). Because NWI maps use the classification system of Cowardin et al. (1979), the wetland types to be monitored must be compatible with this system or additional photo interpretation will be required. The NWI is presently preparing status and trends reports for a number of regions in the United States, including coastal Texas (Warren Hagenbuck, personal communication).

National Wetland Inventory maps are suitable for determining the general location of various types of wetlands and for estimating large scale changes in the extent of wetlands. However, identifying specific boundaries will require site-specific measurements since even a fine line drawn on the 1:24,000 scale NWI maps represents approximately five meters (Mitsch and Gosselink, 1993). National Wetland Inventory maps have been used extensively during the EIS process to identify projects potentially impacting wetlands and to describe trends in the extent of wetlands in specific geographic regions (Dennis Peters, personal communication).

The NOAA C-CAP is developing standardized approaches to classifying and monitoring coastal habitats from satellite thematic mapping (TM) imagery (Pulich and Hinson, 1992). The classification system used by NOAA C-CAP includes Wetland, Open Water, and Upland classes that are further divided into a hierarchical system based on attributes such as water salinity, plant morphology, and landscape structure. Digital satellite imagery data covers larger areas and is available at relatively frequent intervals allowing comparisons to be made over shorter time periods than with aerial photography. Impacts due to catastrophic events as well as long term trends in the extent and distribution of habitats can therefore be evaluated.

The objectives of the GBNEP trends and status project were to: 1) identify specific Galveston Bay wetland plant communities associated with wetland signatures on aerial photographs, and 2) assess the status and trends of wetland and aquatic habitats in Galveston Bay based on mid-1950s, 1979, and 1989 photographs (White and Paine, 1992). Information obtained by the GBNEP sponsored efforts to evaluate wetland loses in the estuary since 1959 will establish a baseline estimate of wetland extent in the area. Surveys conducted in 1990 and 1991 (White and Paine, 1992) can be used to determine how well the Cowardin et al. (1979) system describes wetlands in Galveston Bay.

Pulich and White (1991) studied historic changes in the aerial extent of submerged vegetation in West Bay using aerial photography from 1956, 1965, 1975, and 1987. Other researchers (e.g., White et al., 1985) have also successfully mapped areas of submerged vegetation in Galveston Bay based on aerial photography (Pulich et al., 1991). Although the NWI is based on aerial photography, submerged vegetation has not consistently been identified on the NWI maps. Additional analyses could be conducted, however, following the USFWS photo interpretation, cartographic, and digitizing conventions (USFWS, 1990; USFWS, 1994a; USFWS, 1994b) using existing aerial photography.

Recommended Monitoring Approach

Pulich and Hinson (1992) used C-CAP methodologies to classify and inventory wetland habitats over an area of 170 km^2 in lower West Galveston Bay. White et al. (1993) used NWI maps to classify and inventory wetland and aquatic habitat areas throughout the Galveston Bay estuary. Results from each of these studies indicate that either method would be suitable for monitoring the extent and distribution of freshwater marsh and emergent estuarine marsh in Galveston Bay. Although it may be possible to measure the aerial extent of submerged vegetation using these methods, neither will provide suitable species composition data for this habitat type. It is strongly recommended that the distribution and abundance of individual submerged vegetation species be monitored.

Because of the ability to provide more frequent analysis, the Regional Monitoring Steering Committee selected the C-CAP methodologies for use in the Galveston Bay Regional Monitoring Program. Pulich and Hinson (1992) developed a set of classification methodologies based on C-CAP specifically for application along the upper Texas coast. These methodologies are recommended for all monitoring of habitat extent and distribution under the Galveston Bay Regional Monitoring Program. The classification system used by Pulich and Hinson (1992) includes nine Level 1 subclasses of wetland and upland habitat found in the Galveston Bay area (Table 5-1).

5.1.3 QA/QC Considerations

Hinson et al. (1994) provides an evaluation of two methods used for determining the accuracy of wetland and landcover classification based on TM imagery. Ground-truthing techniques demonstrated that accuracy exceeding 85% could be achieved for 10 major landcover classes using satellite TM imagery. Routine ground-truthing of satellite TM imagery mapping should be conducted to ensure that this level of accuracy is maintained during all habitat monitoring under the Regional Monitoring Program.

Table 5-1. CANDIDATE INDICATORS AND MEASUREMENTS FOR HABITAT PROTECTION

Indicator Habitats	**Measurement**
Marsh	
• All marsh types	Areal extent and distribution % emergent vegetation % open water dominated by aquatic vegetation Marsh edge and interspersion Water duration Open water depth Salinity\ Aquatic organism access
• Brackish marsh	Change in relative sea level-subsidence/erosion
• Salt marsh	Percent *Spartina alterniflora*
Submerged Vegetation • Sea grasses	Areal extent and distribution Biomass Vegetation spp composition PAR Salinity
Oyster reefs	Areal extent and distribution
Colonial waterbird nesting habitat	Number of colonies and distribution # nesting pairs Abundance of predators (e.g., raccoons) Elevation above sea level Connectivity to mainland Indications of human disturbance

White et al. (1993) identify seven species of submerged aquatic vegetation found in the Galveston Bay estuary. Two of these species, turtlegrass *(Thalassia testudinum)* and clovergrass *(Halophila engelmannii)*, are extremely limited in their distributions and may warrant special attention. Because the species composition of submerged aquatic vegetation cannot be determined from aerial photographs or TM imagery, extensive ground truthing will be necessary for this habitat type.

5.2 HABITAT FUNCTION AND VALUE

Function, particularly when referring to wetland habitats, represents the ecological benefits that a habitat provides. Wetland functions, for example, include fish and wildlife habitat, nursery areas, and food web support, among others. Habitat values are a measure of the human benefits that are provided by a habitat. Wetland values include flood control, shoreline protection, and recreational opportunities.

Quantifying habitat function and value allows managers to monitor trends in habitat quality that could not be measured by extent and distribution alone. Presently no agency monitors habitat function or value in Galveston Bay on a routine basis.

5.2.1 Data Use and Limitations

Monitoring the function and value of habitats in Galveston Bay provides information directly supporting a determination of whether the following Resource Management Objective is being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.

Agency Mandates/Objectives

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this the TNRCC develops water quality standards, and regulates point and nonpoint pollution sources. Monitoring data is used by the TNRCC to:

1. Describe existing water quality in streams, reservoirs, and bays

2. Monitor the impact of industrial, municipal, and agricultural point source discharges on water quality

3. Assess water quality impacts resulting from spill events

4. Assess long-term trends in water quality

5. Compare existing water quality and established water quality standards (waste load allocations, water quality standards)

6. Conduct activities and make management decisions pertaining to the Texas Water Code and Federal Clean Water Act (permits, waste load allocations, water quality standards, etc.) (Guillen, 1991).

Revisions made to the Texas Surface Water Quality Standards in 1991 provided a definition of wetlands and included them as waters of the state. In 1994, the TNRCC proposed six categories of wetlands and revisions to the standards applicable to wetlands that include:

1. Narrative criteria for aesthetic, radiological, toxic, nutrient, and salinity parameters

2. Numerical limitations for thermal elevations

3. Fecal coliform limits considered appropriate for contact recreation

4. Site-specific assessment of uses and standards in response to any TNRCC permitting action

5. A description of the antidegradation policy and procedures

6. Numerical criteria to protect aquatic life from acute toxicity and additional numerical toxic criteria where appropriate (TNRCC, 1994).

Existing surface water quality standards are intended to protect the chemical conditions of the water. However, future revisions to the standards that would address the protection of wetland vegetation and habitat are being considered (TNRCC, 1994). In addition to these changes, the TNRCC is in the process of developing biocriteria for state waters based on existing aquatic life subcategories. Biocriteria may require more quantitative measures of aquatic life attributes (e.g., habitat characteristics, species assemblages, and diversity) that are described for the aquatic life subcategories. Quantitative measures of habitat condition could be used in developing and applying biocriteria.

5.2.2 Sampling and Analytical Methods

Existing Assessment Techniques

A number of standardized techniques have been used for assessing habitat function and value including the Wetland Evaluation Technique (WET), Habitat Evaluation Procedure (HEP), and the Wetland Value Assessment Methodology and Community Models. In addition to these generalized procedures for habitat assessment, regionally specific methods have also been developed for some areas. The Chesapeake Bay Program, for example developed the Habitat Requirements for Chesapeake Bay Living Resources which establish habitat criteria for the protection of selected species in the Chesapeake Bay area.

The Wetland Evaluation Technique assesses the suitability of wetland habitat for 14 waterfowl species groups, 4 freshwater fish species groups, 120 species of wetland-dependent birds, 133 species of saltwater fish and invertebrates, and 90 species of freshwater fish. It does not, however, evaluate other important wildlife resources such as game and furbearing mammals (USEPA, 1992). Wetland functions and values are measured by characterizing the physical, chemical, and biological attributes and processes of the wetland (Adamus et al., 1987). Assessments based on WET also include consideration of a wetland's social significance, effectiveness (ability to perform a function), and opportunity to perform a function.

The Habitat Evaluation Procedure was developed by the USFWS for measuring the quality and quantity of habitat available for selected wildlife species. The relative value of a habitat is evaluated based on a comparison of either: 1) the value of different areas at the same point in time; and 2) the value of the same area at different points in time. By combining the two types of comparisons, the impacts on, or improvement in habitat quality as a result of proposed or anticipated land and water use changes on wildlife habitat can be quantified (Leonard and Clairain, 1986). The evaluation involves using the same key habitat components to compare existing habitat conditions and the optimum conditions for the species of interest (USFWS, 1980).

The Wetland Value Assessment (WVA) methodology was developed by the USFWS for use in prioritizing project proposals submitted for funding under the Coastal Wetlands Planning, Protection, and Restoration Act. This technique quantifies changes in wetland quality and quantity that are projected to be brought about as a result of a proposed project. The WVA is based on HEP, but rather than the species oriented approach of HEP, WVA utilizes a community based approach (USFWS, 1991). The WVA was developed specifically for application to the following coastal Louisiana wetland types: fresh marsh (including intermediate marsh), brackish marsh, saline marsh, and cypress-tupelo swamp (USFWS, 1991).

Recommended Monitoring Approach

All of the above described habitat assessment methodologies would require revisions to adapt them to the specific needs of GBNEP. Because WVA was developed for habitats similar to those found in the Galveston Bay estuary, this method has been selected for use in the Galveston Bay Regional Monitoring Program. Procedures for conducting habitat evaluations using WVA are described in Coastal Wetland Planning, Protection, and Restoration Act: Wetland Value Assessment Methodology and Community Models (USFWS, 1991).

The WVA operates under the assumption that optimal conditions for a coastal wetland can be characterized, and that any existing or predicted condition can be compared to that optimum to provide an index of wetland quality (USFWS, 1991). The quality component of a wetland is estimated or expressed through the use of a mathematical model developed specifically for each wetland type. Each model consists of 1) a list of variables that are considered important in characterizing the particular wetland type, 2) a Suitability Index graph for each variable, which defines the assumed relationship between wetland quality and the variable, and 3) a mathematical formula that combines the quality value (Suitability Index) for each variable into a single, overall value for wetland quality; that single value is referred to as the Habitat Suitability Index, or HSI. Use of WVA requires developing a list of variables characterizing the various wetland types found in Galveston Bay and a Suitability Index for each of those variables.

The Wetland Value Assessment models have been developed for determining the suitability of Louisiana coastal wetlands in performing or providing a diverse array of functions and values including, but not limited to: providing resting, foraging, breeding, and nursery habitat to a diverse assemblage of fish and wildlife species; providing storm-surge protection, flood water storage, and water quality functions; and serving in nutrient import/export. Those functions are loosely equated to wetland "quality" in that a wetland that provides or performs those functions and values better or to a greater degree than another may be considered to be of higher "quality" (USFWS, 1991).

5.2.3 QA/QC Considerations

Field testing will be required before the Wetland Value Assessment Methodology can be applied in the Galveston Bay area. Optimal conditions should be characterized for each of the selected indicator habitat types.

CHAPTER 6
SPECIES DISTRIBUTION AND CONDITION

Monitoring the distribution and abundance of selected species provides information to be used in assessing the following Resource Management Objectives:

SP-1: At a minimum, maintain fish and crustacean population levels within 50% of 1975-1985 mean levels.
SP-2: At a minimum, maintain oyster population levels within 50% of 1983-1993 levels.
SP-3: Reduce bycatch within the estuary by 50% by the year 2007, accounting for seasonal patterns.
SP-4: Reduce current levels of fish mortality caused by impingement/entrainment by 50% by the year 2007.
SP-5: Increase populations of endangered and threatened species.
SP-6: By the year 2005 reduce the abundance of selected exotic species, including nutria and grass carp, by 10%.

Information obtained from species population monitoring will also support assessments of four additional Resource Management Objectives:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
HP-6: Improve and protect habitat on 10 major colonial bird nesting sites within 5 years.
WSQ-2: By the year 2004, ensure that all water quality segments within the estuary are in compliance with established dissolved oxygen standards.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, although species population data is not directly applicable to determining compliance with dissolved oxygen (DO) standards, such information will be needed to determine the applicable standard in some areas. The Texas Natural Resource Conservation Commission (TNRCC) is in the process of adopting DO standards based on aquatic life categories (TNRCC, 1994). Placement in an aquatic life category is based on a characterization of the community of organisms supported in a given waterbody. Results of species population monitoring could be used in assigning a waterbody to one of the aquatic life subcategories which will in turn determine what the appropriate DO standard is.

Chapter 6 is divided into 10 sections. Each addresses monitoring of a different community, species, or group of species. Sections 6.1 through 6.5 describe methods for monitoring various species that are recognized for their ecological importance. Sections 6.6 and 6.7 describe methods for monitoring commercially important finfish species and oysters, respectively. Section 6.8 describes the methods used in monitoring fisheries losses due to impingement and entrainment at water intake structures. Monitoring populations of introduced species is described in Section 6.9 and monitoring populations of threatened and endangered species is discussed in Section 6.10.

Specific indicator species have been selected for monitoring pelagic invertebrates (Section 6.2), finfish populations (Section 6.5), and finfish commercial harvest (Section 6.6). A list of these species is provided in each section. Finfish populations and finfish commercial harvest were separated because of the distinctly different methods used to monitor each of these groups and differences in the objectives for the two types of monitoring. However, for some species monitoring data are obtained through both programs. Three introduced species and four threatened or endangered species were selected for monitoring and methods are described separately for each.

6.1 PHYTOPLANKTON BIOMASS

Phytoplankton plays an important role as a primary producer in most estuarine ecosystems, including Galveston Bay. As such, changes in phytoplankton abundance often lead to corresponding changes in the abundance of phytoplankton consumers, particularly filter feeding zooplankton and benthic communities. Because of this relationship, information on phytoplankton biomass is often useful for interpreting changes in these other communities.

Phytoplankton communities are susceptible to a number of anthropogenic influences such as excess or deficient nutrient input and changes in salinity that could be associated with flow diversion. The relatively short life span and high growth potential characteristic of this group means that changes in environmental quality can lead to rapid changes in abundance and biomass. Because different species are favored under various environmental conditions (e.g., differences in salinity and nutrient availability) changes in community structure can provide an early indication of changing conditions in an area. Therefore measures of both community structure and biomass are useful for assessing ambient water quality conditions.

Phytoplankton biomass is most frequently estimated through the measurement of chlorophyll-*a* concentration. Chlorophyll-*a* typically constitutes approximately 1.5 percent of the dry weight of organic matter in phytoplankton and total biomass can be estimated by multiplying chlorophyll-*a* content by 67 (APHA, 1992). The ratio of chlorophyll-*a* to pheophytin-*a* (a degradation product of chlorophyll-*a*) is often used as an indicator of the physiological condition of phytoplankton.

6.1.1 Data Use and Limitations

Phytoplankton monitoring provides information indirectly supporting determinations of whether the following three Resource Management Objectives are being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.

WSQ-2: By the year 2004, ensure that all water quality segments within the estuary are in compliance with established dissolved oxygen standards.

FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, it is inappropriate to estimate annual and seasonal freshwater inflow needs (Objective FW-2) based solely on historic levels. Such an estimate should be based on the condition of various communities found in the estuary under different levels of inflow. Because the phytoplankton community responds quickly to changes in salinity, nutrient availability, or water temperature, this group would provide an excellent indicator of the effects that various levels of freshwater inflow have on the health of the estuary. Changes in the phytoplankton community can provide a similar indirect measure of wetland function and aid in determining the cause of low dissolved oxygen concentrations in a water quality segment. Information from the phytoplankton component of the Regional Monitoring Program can also be useful for selecting appropriate actions necessary to reach these objectives.

Agency Mandates/Objectives

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this the TNRCC develops water quality standards, and regulates point and nonpoint sources of pollution. Monitoring data are used by the TNRCC to:

1. Describe existing water quality in streams, reservoirs, and bays

2. Monitor the impact of industrial, municipal, and agricultural point source discharges on water quality

3. Assess water quality impacts resulting from spill events

4. Assess long-term trends in water quality

5. Compare existing water quality and established water quality standards (waste load allocations, water quality standards)

6. Conduct activities and make management decisions pertaining to the Texas Water Code and Federal Clean Water Act (permits, waste load allocations, water quality standards, etc.) (Guillen, 1991).

The TNRCC is primarily concerned with measuring the physical/chemical characteristics of water for comparison with state standards and criteria and permit limitations. Biological data, however, serve a number of purposes that include identifying appropriate designated uses, assessing water quality standards and criteria, and measuring the ecological impact of changes in water quality. In addition, the TNRCC is presently working to develop biocriteria based on quantitative biological indices used to define aquatic life categories (TNRCC, 1994). Phytoplankton condition and biomass are useful measures of environmental condition provided sufficient long-term data are available for analysis.

Phytoplankton monitoring provides important ancillary information necessary to properly interpret the results of other monitoring program components. It is important that this monitoring effort be coordinated with other program components and that the phytoplankton monitoring data be readily available. This is discussed in greater detail in Section 6.1.2 and in sections describing the methods for these other components of the Regional Monitoring Program (e.g., Section 5.2 Habitat Function and Value).

6.1.2 Sampling and Analytical Methods

This subsection begins with a brief description of monitoring or research programs that measure phytoplankton biomass in Galveston Bay. A monitoring approach has been selected from among these alternatives for use in the Galveston Bay Regional Monitoring Program. The selection was based on an evaluation of data comparability, costs, sensitivity, accuracy, precision, and robustness of the various methods.

Existing Monitoring Programs and Special Studies

Presently the TNRCC is the only agency conducting phytoplankton monitoring in Galveston Bay. Data collected under this program are stored in the Surface Water Quality Monitoring Data Base. The program presently measures chlorophyll-*a* and pheophytin-*a*, but in the past has also measured community structure through direct species counts. Chlorophyll-*a* and pheophytin-*a* are measured at 55 stations four times a year through spectrophotometric analysis of water samples. Community structure was assessed twice a year at 10 stations; however, because of staffing limitations this has not been performed for several years.

Buskey and Schmidt (1992) identify ten short-term studies of phytoplankton communities in Galveston Bay and provide a brief summary of these studies. The majority were conducted during the 1970s and there has been no phytoplankton research since 1985 . Armstrong and Hinson (1973) provides one of few studies describing species composition over a wide area of the Galveston Bay estuary. Other studies have been very limited in their spatial coverage and most were designed to investigate local conditions.

Recommended Monitoring Approach

Chlorophyll-*a* and pheophytin-*a* concentration should be used to monitor phytoplankton biomass for the Galveston Bay Regional Monitoring Program. The methods used by TNRCC are suitable for assessing attainment of the Resource Management Objectives described above and to meet the general objectives of the

Regional Monitoring Plan. Computerized data from this program are available for some stations in Galveston Bay from as far back as 1968 (Guillen, 1991) providing a suitable long-term data set for assessing trends. The TNRCC monitoring program follows procedures outlined in the *Draft Water Quality Procedures Manual* (TWC, 1993) and Method 10200 H from *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).

Sample Collection and Handling

The collection and handling of phytoplankton samples for the Galveston Bay Regional Monitoring Program will be done in accordance with the methods used by TNRCC. Three separate collection techniques to obtain samples for analysis of community structure and biomass are described in the TWC (1993). Samples may be collected using either a plankton net or a Kemmerer or Van Dorn sample bottle. The appropriate collection technique is determined by plankton density and whether or not the sample is to be used for measuring nannoplankton (organisms < 40 microns in diameter) abundance.

Samples for analysis of chlorophyll-*a* concentration should be collected using a Kemmerer or Van Dorn sample bottle as described in the TWC (1993). However, no fixatives should be applied to the samples and they should be kept in the dark at 4° C to prevent the chlorophyll values from being altered during transport and storage.

Sample Analysis

Chlorophyll-*a* concentrations should be measured through spectrophotometric analysis of samples as described in *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).

Supporting Ancillary Information

The TNRCC program collects samples for the analysis of a suite of water quality and biological parameters at the same time that phytoplankton samples are collected. Water column variables that are measured as part of the TNRCC program, and should therefore be included in the Galveston Bay Regional Monitoring Program, are listed in Table 6-1. These ancillary data are important for properly interpreting changes in the phytoplankton community and for making comparisons with existing data. The methods to be used in measuring these other parameters are described in the *Draft Water Quality Monitoring Procedures Manual*

Table 6-1. PHYTOPLANKTON MONITORING PARAMETER LIST

Secchi Depth	Orthophosphate
pH	Nitrite-N
Water Temperature	Nitrate-N
Dissolved Oxygen	Ammonia-N
Salinity	Total Phosphorus
Biochemical Oxygen Demand	Pheophytin-*a*
Total Suspended Solids	Chlorophyll-*a*

Additional Considerations

It is recommended that phytoplankton community structure be measured periodically, particularly if significant changes in nutrient availability, zooplankton community structure, or benthic infauna community structure are detected. Such sampling should be done at all stations where phytoplankton biomass is measured in conjunction with that sampling. It is recommended that community structure be measured through the identification and counting of individuals as described in TWC (1993). A minimum of three subsamples should be drawn from each sample and analyzed in a 1-ml plankton chamber. Standard taxonomic references to be used in community descriptions are listed in the TWC (1993).

It is important to coordinate the phytoplankton monitoring program with measurements of the Bay's physical/chemical and biological characteristics. Phytoplankton communities in Galveston Bay show considerable seasonal and long-term variability and are characterized by a series of small blooms that occur throughout the year (Buskey and Schmidt, 1992). This variability may be influenced by any of a number of factors including light availability, nutrients, and water temperature. These factors are in turn influenced by a suite of other environmental factors. By coordinating sampling among the various Regional Monitoring Program components, the value of the data for making management decisions will be greatly enhanced.

Alternative Monitoring Approaches

Spectrophotometric measurement of chlorophyll-*a* provides a relatively fast, simple, and cost effective determination of the active photosynthetic pigments in phytoplankton. Although the method provides reproducible results, sensitivity and accuracy are effected by accessory pigments present at variable levels in different species of phytoplankton. Despite variability due to the presence of these accessory pigments, spectrophotometric determinations provide greater accuracy than alternatives such as cell counts, total cell volume estimates, protein estimates, and dry weight determinations.

Two alternative analytical techniques, fluorometry and high-performance liquid chromatography (HPLC), can be used to measure chlorophyll-*a* concentrations.

HPLC can also be used to obtain additional information about the major taxonomic groups in a sample based on the relative proportions of different pigments characteristic of the groups (Buskey and Schmidt, 1992).

Fluorometric Analysis: Submersible fluorometers enable *in situ* measurement of chlorophyll concentration, eliminating the need to transport samples back to the laboratory for analysis. Fluorometric techniques are also are more sensitive than spectrophotometry (APHA, 1992). The use of a submersible fluorometer will allow for faster data collection, integrated electronic storage of the data, simultaneous collection of associated water column data (such as, transmissivity, dissolved oxygen, depth, temperature, and conductivity), and, in most cases, lower cost. Submersible fluorometers are available from Sea Tech, Inc., Corvalis, OR at a cost of about $10,000.

Because both fluorometric and spectrophotometric methods measure chlorophyll-*a* concentrations, the resulting data are comparable. However, samples analyzed using different techniques should not be combined for statistical analysis. If the analytical technique is changed, it is recommended that samples be analyzed using both methods for at least one year.

Fluorometric analysis of chlorophyll-*a* as a measure of phytoplankton biomass provides the following advantages over spectrophotometric methods presently being used:

1. lower cost
2. *in situ* measurement
3. faster data collection
4. greater sensitivity.

These benefits should be balanced against the following disadvantages of changing to fluorometric analysis:

1. inability to statistically compare results with historic data
2. initial costs for new equipment and training
3. increased maintenance costs of field equipment.

High-Performance Liquid Chromatography (HPLC): A second alternative to spectrophotometric methods is to use HPLC analytical techniques. Although this method provides the most accurate measurement of chlorophyll, it is also the most expensive. With HPLC, measurements of phytoplankton pigments can be made to estimate the relative composition of major taxonomic groups in the samples (Buskey and Schmidt, 1992). This type of analysis can be performed more quickly, and therefore less expensively, than direct counts of species and individuals. Some of the additional cost may be offset if this provides a suitable estimate of community composition. Detailed information on per sample costs and specific statements of program objectives (i.e., what level of taxonomic change indicates a change in Galveston Bay) would be necessary to evaluate the cost advantages of using this HPLC method.

High-Performance Liquid Chromatography measurements of chlorophyll concentration provide the following advantages over the approach presently being used:

1. measurement of various pigments present in phytoplankton (allows determination of major species groups present in the sample)

2. a lower cost measure of community structure than direct species count methods.

These benefits must be balanced against a significantly higher overall cost for analysis.

6.1.3 QA/QC Considerations

Phytoplankton sampling conducted under the Galveston Bay Regional Monitoring Program will be subject to the Quality Assurance/Quality Control procedures outlined in the *Draft Water Quality Monitoring Procedures Manual* (TWC, 1993). The program includes annual quality assurance visits by the Water Quality Monitoring Unit, an annual Water Quality Monitoring Workshop, the collection of field and laboratory quality control samples, and data entry quality assurance checks. The TNRCC quality assurance program for laboratories analyzing water quality monitoring samples is described in a separate document.

Annual quality assurance visits will be conducted at any office participating in the Galveston Bay Regional Monitoring Program to ensure that personnel are using acceptable monitoring procedures and that these procedures are consistent with those selected by GBNEP.
Quality control is provided through the analysis of split and duplicate samples. Split samples, made by splitting the contents of a 2-1/2 gallon sample at the time of collection, are used to assess variability introduced during preservation, transport, and analysis. Field duplicates are samples collected sequentially at a station. Differences between these samples indicate the amount of variability due to field handling and transport procedures. One split sample and one duplicate sample are to be collected and analyzed for every 40 samples collected in the field. More specific procedures for collecting these samples and submitting them for analysis are contained in the *Draft Water Quality Monitoring Procedures Manual* (TWC, 1993).

Additional Considerations

A high level of natural variability is typically observed among phytoplankton samples. Variability in measurements due to field heterogeneity is quantitatively determined by the analysis of replicate field samples. Analysis of replicate samples is necessary for assessing the reliability of spatial and temporal comparisons. It is recommended that a minimum of three replicate samples be collected at each station (U.S. EPA, 1992).

Laboratory performance and calibration should be verified at the beginning and periodically (every 20 samples) during the time analyses are performed through the use of standards or blanks. Chlorophyll quality control samples can be obtained from the U.S. EPA Environmental Monitoring Support Laboratory in Cincinnati, Ohio. Standards can be used to evaluate performance without interference from natural variability. The *Interim Guidance on Quality Assurance/Quality Control (QA/QC) for Estuarine Field and Laboratory Methods* (U.S. EPA, 1985) provides a standard procedure for chlorophyll measurements.

6.2 INVERTEBRATE SPECIES

A diverse group of invertebrates are present in the Galveston Bay estuary. Many are important for their commercial/recreational value or their role as intermediate consumers in the ecosystem. The Species Population Protection Task Force of GBNEP has identified the following three species as indicators for this group:

- white shrimp *(Penaeus setiferus)*
- brown shrimp *(Penaeus aztecus)*
- blue crab *(Callinectes sapidus)*.

Many species of invertebrates are dependent on wetland habitats during a critical period of their life cycle (e.g., spawning, juvenile stages). Changes in the extent and quality of wetlands may therefore lead to changes in the abundance of many invertebrate species (particularly their juvenile stages). Members of this group frequently exhibit planktonic larval stages whose survival and dispersal can be strongly influenced by the magnitude and timing of freshwater inflow.

6.2.1 Data Use and Limitations

Monitoring invertebrate populations provides information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-1: At a minimum, maintain fish and crustacean population levels within 50% of 1975-1985 mean levels.

Invertebrate data will also support determinations of whether the following Resource Management Objectives are being met:

SP-3: Reduce bycatch within the estuary by 50% by the year 2007, accounting for seasonal patterns.
SP-4: Reduce current levels of fish mortality caused by impingement/entrainment by 50% by the year 2007.
HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, evaluating the impacts of bycatch or impingement/entrainment on populations must include consideration of changes in the abundance of the species being considered. Invertebrate data can also support assessments of wetland function because many of these species are dependent on wetland habitats for all or part of their life. Similarly, because many of these species are strongly influenced by changes in freshwater inflow, changes in their abundance can be used to determine annual and seasonal inflow needs.

Agency Mandates/Objectives

The Texas Parks and Wildlife Department (TPWD) monitors populations of selected invertebrates as part of its Resource Monitoring Program. The objectives of that program are:

- Develop long-term trend information on finfish and shellfish population abundance and stability

- Monitor environmental factors which may influences finfish and shellfish availability

- Determine growth, mortality and movement of selected species through recapture of tagged fish and by scale analysis.

The NMFS Baseline Production Program is administered by that agency's Galveston Laboratory. Research is conducted at the Galveston Laboratory to study relationships between various habitats in Galveston Bay and fisheries production. Ongoing projects address (Zimmerman et al., 1992):

- Measuring habitat utilization by selected fish and pelagic invertebrate species

- Identifying factors that affect juvenile abundance for selected fish and pelagic invertebrate species

- Creating salt marshes that benefit important fisheries species

- Developing an estuarine information and data inventory.

6.2.2 Sampling and Analytical Methods

This subsection begins with a brief description of sampling and analytical methods that have been used to measure the abundance and distribution of invertebrate species in Galveston Bay. A monitoring approach has been selected from among these alternatives for use in the Galveston Bay Regional Monitoring Program. The selection was based on an evaluation of data comparability, costs, sensitivity, accuracy, precision, and robustness of the various methods.

Existing Monitoring Programs

Presently the TPWD Resource Monitoring Program and the NMFS Baseline Production Program measure invertebrate populations in Galveston Bay. The TPWD Resource Monitoring Program collects 45 gill net, 20 trawl, and 20 bag seine samples in Galveston Bay monthly. Trawl and bag seine samples are collected monthly, gill net samples are collected semiannually. Sampling sites are randomly selected from a grid system. Data collected include species name, number of individuals, size, weight (occasionally), sex, and maturity. Osborn et al. (1992) provide a description of data collected by the Resource Monitoring Program and detailed statistical analyses for a large portion of this data.

The NMFS Baseline Production Program collects samples at various stations in West Bay marshes using drop traps. Sampling is conducted between March and July on a biweekly basis. Data collected includes the species name, number of individuals, and biomass of selected target species. In the future this program will be expanded to sample 30 stations located throughout Galveston Bay.

Recommended Monitoring Approach

The methods used by the TPWD Resource Monitoring Program are best suited for meeting the Resource Management/CCMP Objectives stated above. The Resource Monitoring Program provides the best long-term data available for assessing Species Population Objective, SP-1. Standardized methods have been used for gill net sampling since 1975, for bag seine sampling since 1977, and for otter trawl sampling since 1982 (Osborn et. al., 1992).

It is recommended that invertebrate sampling for the Galveston Bay Regional Monitoring Program be conducted in accordance with the methods used by TPWD's Resource Monitoring Program. Four alternative sampling techniques (18.3 m long bag seine, 60.9 m long beach seine, 182.9 m long gill net, or 6.1 m wide otter trawl) are available. Detailed descriptions of each gear type and its operation are contained in the *Marine Resources Monitoring Operations Manual* (TPWD, 1993a).

Sampling stations are selected randomly from a grid system to ensure an equal chance of sampling each section of shoreline and open bay water. The appropriate sampling technique is selected based on the time of year and location of the sampling station. Sampling periods and environmental conditions (e.g., water depth, amount of obstruction, etc.) under which each sampling technique is to be used are described in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

All organisms greater than 5 mm in length are to be identified to the species level and counted. If an organism can not be identified within two hours it is to be identified to the lowest possible taxonomic level and preserved for later identification to the species level. For bag seine and beach seine samples, 19 randomly selected individuals of each pelagic invertebrate species are to be measured. For gill net samples 19 randomly selected individuals of each pelagic invertebrate species from each mesh size are to be measured.

Information to be recorded at the beginning and completion of sampling are listed in Table 6-2. This ancillary information is necessary to properly interpret changes in the abundance and distribution of invertebrate species and ensures that valid comparisons are made when the data is evaluated.

Species abundance data is recorded on a Marine Resource Monitoring Data Sheet and ancillary information is recorded on a Marine Resource/Harvest Investigation Meteorological and Hydrological Data Sheet. Example copies of these data sheets are included in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a). Codes for identifying sampling grid locations, species, sex and age of individuals, and the collection method used are also contained in the *Operations Manual.*

Alternative Monitoring Approaches

Osborn et al. (1992) recommend stratifying gill net and bag seine sampling by location as a means of improving program results. Although this issue is related to sampling strategy rather

Table 6-2. INVERTEBRATE MONITORING PARAMETER LIST

Cloud Cover
Lighting Conditions (i.e., day, night, twilight)
Wind Speed and Direction
Barometric Pressure
Rainfall (y or n) and Fog (y or n)
Wave Height
Tide Condition (slack-high, slack-low, ebb, flood, spring, neap)
Shallow Water Depth (nearest 0.1 m)
Deep Water Depth (nearest 0.1 m)
Maximum Water Depth at Station (nearest 0.1 m)
Water Temperature (nearest 0.1° C)
Dissolved Oxygen (nearest 0.1 ppm)
Salinity (nearest 0.1%)
Turbidity (NTU)
Bottom Type (clay, silt, sand, shell, gravel, rock)

than sampling method, it is an important consideration for the Galveston Bay Regional Monitoring Program. By stratifying invertebrate sampling efforts, a certain level of comparability with other Regional Monitoring Program components could be ensured. Furthermore, by stratifying sampling efforts it may be possible to ensure that the data gathered is suitable for use by other agencies (e.g., TNRCC wetlands sampling) so that cost sharing is possible.

Future monitoring under the Regional Monitoring Program may require sampling inside vegetated wetland habitats to better assess wetland function. The methods used by the TPWD Resource Monitoring Program are suitable for meeting the above stated objectives, but would be difficult to apply in these areas. Two alternative sampling techniques, drop traps and flume nets, might be appropriate for future sampling of invertebrates in vegetated areas.

Drop traps have been successfully used to sample a variety of shallow water habitats including marshes, submerged aquatic vegetation, oyster reefs, and bare mud and sand bottoms (Zimmerman et al., 1992).

Kneib and Wagner (1994) used flume weirs to investigate the use of intertidal marshes by fish and invertebrates on Sapelo Island, Georgia. The system they used consisted of a series of wooden support posts defining a pentagon-shaped sampling area of 100 m^2 (Kneib and Wagner, 1994). Removable screen panels (1.2 mm square mesh) were inserted between the posts to enclose the sampling area and capture nekton in the marsh. Pits fitted with removable screen baskets were installed at the lower apex of the pentagon to capture nekton as they moved out of the enclosure during the ebbing tide. Marsh use during different tidal stages could be assessed by installing the panels at different tidal stages. Kneib (1991) provided details on flume weir construction and operation.

6.2.3 QA/QC Considerations

Population data collected using nets of any form is only comparable if net mesh size and fishing effort are standardized. Gill net, trawl, beach seine, and bag seine data are standardized by catch per unit effort based on the size of the area sampled and fishing time. It is also desirable to standardize sampling by tidal stage and time of day to the extent practicable as most estuarine invertebrate species demonstrate a great deal of tidal and diurnal movement that must be accounted for. Although noise introduced to the data due to these behavioral patterns can be accounted for, a much larger data set will be required to achieve the same level of accuracy in estimates.

Consistency in the taxonomic identification of invertebrates can best be achieved through initiating a regional taxonomic program and establishing a reference collection. Regional taxonomic workshops should be conducted on a regular basis (e.g., biennially) with all agencies participating in the Galveston Bay Regional Monitoring Program attending. The TPWD should be responsible for establishing a reference collection including, at a minimum, examples of all species included in their coding system.

The TPWD *Marine Resource Monitoring Operations Manual* describes protocols for data submission and editing that should be followed during all pelagic invertebrate sampling conducted as part of the Regional Monitoring Program. The *Operations Manual* also describes computer data field checks that provide additional quality assurance. Routine equipment checks should be conducted at the beginning and completion of each sampling effort.

6.3 BIRD POPULATIONS

The Galveston Bay estuary is home to a number of important bird species throughout the year. The area also provides important nesting and wintering habitat for a large number of migratory species. Birds fill a variety of roles in the trophic structure of an ecosystem and may, depending on the species, be primary consumers, secondary consumers, or top carnivores. Because of their diversity and the wide range of ecological roles filled by birds, monitoring of this group is essential to measuring the health of the estuary.

Three functional groups (shorebirds, migratory waterfowl, and colonial nesting waterbirds) have been identified for monitoring bird populations in the Galveston Bay area. Although species will be counted separately, similarities among the members of these groups make it reasonable to conduct surveys of their abundances simultaneously using the same techniques. The aerial extent and condition of colonial nesting waterbird habitat will also be monitored under the Regional Monitoring Program. This group has very specific nesting habitat requirements and typically will return to specific sites each year to nest. For this reason they are very susceptible to development and habitat loss.

6.3.1 Data Use and Limitations

Information on the abundance and distribution of bird populations and the extent and condition of colonial nesting waterbird habitat will be used to determine whether the following Resource Management Objective is being met:

SP-5: Increase populations of endangered and threatened species.

Results from this component of the Regional Monitoring Program will also support a determination of whether the following Resource Management Objectives are being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
HP-6: Improve and protect habitat on 10 major colonial bird nesting sites within 5 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, measurement of wetland use by certain bird species can provide a measure of wetland function. Similarly, certain bird species use freshwater habitats for nesting and/or feeding and changes in their abundance could provide one measure for estimating freshwater inflow needs.

Agency Mandates/Objectives

The Texas Parks and Wildlife Department (TPWD), in conjunction with the U.S. Fish and Wildlife Service (U.S. FWS) and the Texas Colonial Waterbird Society (TCWS), conduct an annual survey of colonial nesting waterbirds along the Texas Coast. The Texas Colonial Waterbird Census (TCWC) is intended to provide:

1. Comparative data suitable for identifying specific areas that deserve more intensive study
2. An annual indicator of conditions at known nesting sites (Wagner and Lange, undated).

6.3.2 Sampling and Analytical Methods

Existing Monitoring Programs

Colonial Nesting Waterbirds: The Texas Colonial Waterbird Census (TCWC) provides the best existing monitoring information for the colonial nesting waterbird functional group. The TCWC has censused breeding pairs at colonial waterbird nesting sites within 15 km of the Texas coast since 1973. Surveys are conducted annually during a two-week period beginning the last week of May. Standardized procedures have consistently been followed during the censuses and established data forms have been used for recording results since 1986. Most surveys in the vicinity of Galveston Bay are ground counts made by two to four people viewing colonies on foot or from a boat. Aerial surveys have also been conducted at a number of sites (Slack et al., 1992).

Shorebirds: Until recently, the U.S. FWS, Clear Lake office, conducted irregular monthly surveys of shorebird feeding habitats in the vicinity of Bolivar Flats. This sampling, because it was conducted monthly, provides much more reliable estimates of population size than annual surveys (Slack et al., 1992).

Migratory Waterfowl: TPWD in conjunction with U.S.FWS, has conducted an annual Mid-winter Waterfowl Survey since 1973. This survey consists of one systematic census conducted along transects, and another less systematic census of counting birds at selected locations. These data provide information on waterfowl abundance by species and transect or location. Such information can be used as an index of changes in the relative abundance of species and to assess trends in use patterns within the Galveston Bay area.

Colonial Nesting Waterbird Habitat: Colonial nesting waterbirds utilize two general types of habitat for nesting. Ground nesting species prefer more open areas, often beaches or gravel bars. Tree and shrub nesting species prefer dense thickets of vegetation, often stands of emergent vegetation or large woody vegetation. Presently there is no monitoring of either habitat type in Galveston Bay.

Recommended Monitoring Approach

Colonial Nesting Waterbirds: It is recommended that colonial nesting waterbirds be monitored according to the TCWC protocols.

Shorebirds: It is recommended that shorebirds be monitored according to the protocols used in the shorebird surveys at Bolivar Flat. It is further recommended that sampling be reinstated at Bolivar Flat and that additional sites be selected for monitoring. These should include, but not be limited to, San Louis Pass and the Big Reef area.

Migratory Waterfowl: It is recommended that migratory waterfowl populations be monitored according to the protocols used in the annual Mid-winter Waterfowl Survey.

Colonial Nesting Waterbird Habitat: It is recommended that ten percent of the colonial nesting waterbird sites surveyed during the TCWC be selected for measuring the aerial extent and condition of both types of colonial waterbird nesting habitat (i.e., ground nesting and tree/shrub nesting sites). It is suggested that only sites which are at least 25-meter long and 10-meter wide be sampled and that sites be selected randomly each year. The recommended survey period is between the second Monday in February and the second Monday in March, prior to the start of the nesting season.

Measuring aerial extent and establishing transects: The first task at each site will be defining site boundaries and measuring the aerial extent of the site. It is recommended that boundaries be defined by evidence of the previous year's use (e.g., old nests). After boundaries are established, transects perpendicular to the long axis of the site can be marked by stakes placed at 5-meter intervals along opposite boundaries. It is recommended that the transects to be sampled are selected at random from among all available transects such that 10 percent of the transects are sampled, with no fewer than 5 total. It is also recommended that at least two stations be sampled along each transect. These stations can be selected at random along the length of the transect. It is suggested that ground cover measurements be based on 0.5-meter square plots placed at the centerpoint of each station.

Table 6-3 provides an initial list of suggested parameters to measure at each site. This initial list may be modified by the Species Population Protection Task Force as additional information indicating other important variables becomes available. Height above high tide line should be determined by measuring the vertical distance between the base of the nesting site and the upper limit of the debris line.

Table 6-3. COLONIAL NESTING WATERBIRD HABITAT PARAMETER LIST

Ground Nesting:

- Percent cover
- Predominant plant species present (>10 %)
- Substrate type (sand, gravel, etc.)
- Height above high tide line
- Distance from water

Tree/Shrub Nesting:

- Percent cover
- Predominant plant species present (>10 %)
- Diameter breast high (large woody vegetation only)
- Substrate type (sand, gravel, etc.)
- Height above high tide line
- Distance from water

In addition to the parameters listed in Table 6-3, any potential nest predators or signs of nest predators observed during the survey should be noted. This includes fire ants or fire ant nests found in the area. If fire ants are numerous an estimate of their density should be made. Fire ant colonies should be identified and their location in the nesting area described on a map of the area.

Additional Considerations

Slack et al. (1992) found data from the TCWC to be suitable for trend analysis of species regularly encountered during the surveys. They note, however, that the program does not provide a measure of observer effort. Future monitoring conducted as part of the Regional Monitoring Program should include measures of the time and area censused by observers.

As more species specific information on colonial nesting waterbirds becomes available it may be desirable to stratify sampling by species and focus efforts on selected species (e.g., listed threatened or endangered species). A list of habitat requirements for these species could be developed based on available literature and used to identify additional parameters to be measured and to help prioritize sampling.

6.3.3 QA/QC Considerations

It is recommended that anyone participating in bird surveys as part of the Regional Monitoring Program participate in taxonomic identification workshops prior to surveys. These workshops could provide instruction in call identification as appropriate. It is also recommended that workshops describing colonial nesting waterbird habitat sampling be conducted to familiarize participants with techniques used to measure the selected parameters, identify key plant and animal species, and record data.

6.4 ALLIGATOR POPULATIONS

The American alligator (*Alligator mississippiensis*) is a large, wetland dependent, commercially important, vertebrate predator. As such, alligator populations are very much influenced by a variety of human activities including development of wetlands, pollution, and over hunting. Large predators, feeding at higher trophic levels, are also more susceptible to the impacts of biomagnifying pollutants that might be present in the environment. Because changes in the abundance and distribution of alligator populations reflect habitat condition and a number of anthropogenic impacts, this species was selected as an indicator species in the Galveston Bay Monitoring Plan.

6.4.1 Data Use and Limitations

Information obtained from monitoring alligator populations will support an assessment of the following Resource Management Objective:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.

Agency Mandates/Objectives

The Texas Parks and Wildlife Department is responsible for regulating the annual alligator harvest in Texas. This requires information on the present status of alligator populations and their recruitment rates.

6.4.2 Sampling and Analytical Methods

The TPWD conducts night count surveys of alligators and helicopter surveys of alligator nests along the Texas coast. Established transects are located in the marshes adjacent to East Bay and Trinity Bay (Slack et al., 1992). Surveys were conducted annually from 1980 to 1984 and triennially since 1985. Night counts are conducted by two observers using spotlights to locate individuals from a boat. Nest counts are made along 91 m wide transects of variable length from an altitude of 91 m. Transects are spaced at 1.6 km or 4.8 km intervals. Surveys are conducted in May when vegetative growth in the marshes is low. During night counts efforts are made to standardize lighting equipment.

Recommended Monitoring Approach

The TPWD nest count and night count survey methods are suitable for monitoring changes in alligator populations in the Galveston Bay estuary. However, greater standardization of transect locations and sampling effort during nest counts would provide more meaningful data for little additional cost. The number and location of transects surveyed during nest counts was not consistent preventing direct temporal comparisons of the transects (Slack et al., 1992). Reducing the frequency of sampling from annual to triennial (due to funding limitations) limits the ability of the monitoring program to rapidly detect changes in alligator populations.

The following procedures for nest count surveys of alligator populations conducted as part of the Regional Monitoring Program are required:

- Sampling Locations - detailed description (include maps) of transect locations

- Transect Specifications - transects are 91 m in width. Lengths vary in accordance with habitat extent

- Flight Procedures - altitude is 91 m. Speed and minimum acceptable visibility are to be specified

- Survey Procedures - a detailed description of how nests are identified (i.e., presence of alligators, minimum size of depression, etc.), number of surveyors on plane, responsibilities of surveyors, record keeping procedures are to be specified.

For night alligator count surveys, these parameters and procedures must be established:

- Sampling Locations - detailed description (include maps) of transect locations
- Transect Specifications - description of the length and width of transects
- Boat Operation - boat speed, navigational method, distance and water depth
- Survey Procedures - lighting (power, number of lamps), number of surveyors, responsibilities of surveyors, record keeping procedures are to be specified.

All individuals or nests observed within the defined transect area are counted. The size of individuals should be estimated to the nearest 0.5 m during night counts. Any distinguishing characteristics are to be noted. The condition of individuals should be recorded when alligators show evidence of disease or physical damage. The information listed in Table 6-4 should be recorded on the standard Alligator Night Count data sheet for each individual observed.

Table 6-4. ALLIGATOR MONITORING PARAMETER LIST

Air Temperature*
Water Temperature
Location
Predominant Vegetation
Activity (resting, hunting, feeding, etc.)

*Taken only at beginning and completion of sampling.

Additional Considerations

Conducting multiple surveys during each sampling year is recommended as a way to increase the ability of the program to detect meaningful changes in alligator populations (Slack et al., 1992).

6.4.3 QA/QC Considerations

Population estimates based on direct observations in the field are subject to a great deal of variability associated with differences among samplers and environmental conditions at the time of sampling (i.e., weather/visibility). At least two surveyors, each making independent counts, should be present during every survey. Sampling protocols (e.g., transect width and length, boat speed) should be strictly adhered to.

6.5 FINFISH POPULATIONS

Monitoring fish community structure provides *in situ* measures of the estuarine habitat and provides a powerful tool for evaluating spatial and temporal effects of anthropogenic and natural disturbances. Fish community data can be used to assess the effectiveness of pollution abatement programs and monitor long-term trends in environmental quality. Information about the population characteristics of finfish species is needed to evaluate regulations and management programs.

The Species Population Protection Task Force of GBNEP identified the following three fish species to be monitored as indicators for this group:

- bay anchovy *(Anchoa mitchilli)*
- Atlantic croaker *(Micropogonias undulatus)*
- gulf menhaden *(Brevoortia patronus)*

6.5.1 Data Use and Limitations

Finfish population monitoring provides information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-1: At a minimum, maintain fish and crustacean populations within 50% of 1975-85 mean levels.

Meeting this objective will require monitoring data of sufficient precision to detect changes of the indicated magnitude (i.e., 50 percent) and a comparable estimate of historic (1975-85) population size. Data must therefore be collected using methods that are comparable with historic data.

Finfish population monitoring also provides information supporting determinations of whether the following Resource Management Objectives are being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

Agency Mandates/Objectives

The TPWD monitors finfish populations as part of its Resource Monitoring Program. The objectives of that program are:

- Develop long-term trend information on finfish and shellfish population abundance and stability

- Monitor environmental factors which may influence finfish and shellfish availability

- Determine growth, mortality and movement of selected species through recapture of tagged fish and by scale analysis (McEachron, 1991).

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this TNRCC develops water quality standards, and regulates point and nonpoint pollution sources.

The TNRCC is primarily concerned with measuring the physical/chemical characteristics of water for comparison with state standards and criteria and permit limitations. Biological data, however, serve a number of purposes that include identifying appropriate designated uses, assessing water quality standards and criteria, and measuring the ecological impact of changes in water quality. In addition, the TNRCC is presently working to develop biocriteria based on quantitative biological indices used to define aquatic life categories (TNRCC, 1994). Changes in finfish populations provide a useful measure of environmental condition.

The USEPA Environmental Monitoring and Assessment Program (EMAP) was developed to periodically assess and document the condition of the Nation's ecological resources with a regional scope appropriate to large-scale environmental problems. The goals of EMAP are to:

- Estimate the current status, trends, and changes in selected existing and newly-developed indicators of the condition of the Nations ecological resources

- Estimate the distribution and extent of the Nation's ecological resources

- Identify associations between selected indicators of natural and anthropogenic stresses and indicators of the condition of ecological resources (Tetra Tech, 1994).

The NMFS Baseline Production Program is administered by that agency's Galveston Laboratory. Research is conducted at the Galveston Laboratory to study relationships between various habitats in Galveston Bay and fisheries production. Ongoing projects address:

- Measuring habitat utilization by selected fish and invertebrate species

- Identifying factors that affect juvenile abundance for selected fish and pelagic invertebrate species

- Creating salt marshes that benefit important fisheries species

- Developing an estuarine information and data inventory (Zimmerman et al., 1992).

6.5.2 Sampling and Analytical Methods

Existing Monitoring Programs

The TPWD Resource Monitoring Program collects 45 gill net, 20 trawl, and 20 bag seine samples in Galveston Bay monthly. Trawl and bag seine samples are collected monthly, gill net samples are collected semiannually. Sampling sites are randomly selected from a grid system. Data collected include species name, number of individuals, size, weight (occasionally), sex, and maturity. Large live fish are tagged and released for growth and mortality estimates (Tetra Tech, 1994). Osborn et al. (1992) provide an analysis of results from the Resource Monitoring Program including detailed statistical analyses for a large portion of the data.

The TNRCC nekton sampling program samples 10 stations twice each year and three additional stations annually. A variety of methods are used to collect samples including: fishing rod, trotline, throwline, or handline; twenty-foot minnow seine (1/4 inch mesh); gill net; fish traps; trawl; cast net; water intake screens; backpack electrofisher; and boat mounted electrofisher. Data collected include identification of species and number of individuals. Samples may be retained for later identification or analysis of tissue contaminant concentrations.

The NMFS Baseline Production Program collects samples at various stations in West Bay marshes using drop traps. Sampling is conducted between March and July on a biweekly basis. Data collected include species name, number of individuals, and biomass of selected target species. In the future this program will expand to sample 30 stations located throughout Galveston Bay.

Recommended Monitoring Approach

The TPWD Resource Monitoring Program provides the most complete data set describing fish community and population characteristics for the Galveston Bay estuary. Gill net samples have been collected in the estuary since 1975, bag seines since 1977 and otter trawl samples since 1982. The methods used in TPWD's Resource Monitoring Program should be followed during all fish community and population monitoring conducted as part of the Galveston Bay Regional Monitoring Program. These methods are described in detail in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

Sample Collection and Handling

Sampling conducted to monitor changes in the abundance and distribution of finfish populations for the Galveston Bay Regional Monitoring Program should be done in accordance with the methods of TPWD's Resource Monitoring Program. Four alternative sampling techniques (18.3 m long bag seine, 60.9 m long beach seine, 182.9 m long gill net, or 6.1 m wide otter trawl) are available. Detailed descriptions of each gear type and its operation are contained in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

Sampling stations are selected randomly from a grid system to ensure an equal chance of sampling each section of shoreline and open bay water. The appropriate sampling technique is selected based on the time of year and location of the sampling station. Sampling periods and environmental conditions (e.g., water depth, amount of obstruction, etc.) under which each sampling technique is used are described in TPWD (1993a).

Sample Analysis

All organisms greater than 5 mm in length should be identified to the species level and counted. If an organism can not be identified within two hours it should be identified to the lowest possible taxonomic level and preserved for later identification to the species level. For bag seine and beach seine samples 19 randomly selected individuals of each fish species should be measured. For gill net samples 19 randomly selected individuals of each fish species from each mesh size should be measured. Special processing procedures are described for tarpon, snook, striped and hybrid bass, and grass carp in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

Supporting Ancillary Information

Information to be collected at the beginning and completion of sampling are listed in Table 6-5. This ancillary information is necessary to properly interpret changes in the abundance and distribution of fish species and ensures that valid comparisons are made when the data is evaluated.

Table 6-5. FISH COMMUNITY MONITORING PARAMETER LIST

Cloud Cover
Lighting Conditions (i.e., day, night, twilight)
Wind Speed and Direction
Barometric Pressure
Rainfall (y or n) and Fog (y or n)
Wave Height
Tide Condition (slack, ebb, flood)
Shallow Water Depth (nearest 0.1 m)
Deep Water Depth (nearest 0.1 m)
Maximum Water Depth at Station (nearest 0.1 m)
Water Temperature (nearest 0.1° C)
Dissolved Oxygen (nearest 0.1 ppm)
Salinity (nearest 0.1%)
Turbidity (NTU)
Bottom Type (clay, silt, sand, shell, gravel, rock)

Data Reporting

Species abundance data are recorded on Marine Resource Monitoring Data Sheets and ancillary information is recorded on Marine Resource/Harvest Investigation Meteorological and Hydrological Data Sheets. Example copies of these data sheets are included in TPWD (1993a). Codes for identifying sampling grid locations, species, sex and age of individuals, and the collection method used are also contained in the *Operations Manual.*

Alternative Monitoring Approaches

Osborn et al. (1992) recommend stratifying gill net and bag seine sampling by location as a means of improving program results. Although this issue is related to sampling strategy rather than sampling method, it is an important consideration for applying these methods to the Galveston Bay Regional Monitoring Program. By stratifying fish sampling efforts, a certain level of comparability with other Regional Monitoring Program components could be ensured. Furthermore, by stratifying sampling efforts it is possible to ensure that data are suitable for use by other agencies (e.g., TNRCC wetlands sampling) so that cost sharing is possible.
Future monitoring under the Regional Monitoring Program may require sampling inside vegetated wetland habitats to better assess wetland function. The methods used by the TPWD Resource Monitoring Program are suitable for assessing the above stated objectives, but would be difficult to apply in these areas. Two alternative sampling techniques, drop traps and flume nets, might be appropriate for future sampling of fish in these areas.

Drop traps have been successfully used to sample a variety of shallow water habitats including marshes, submerged aquatic vegetation, oyster reefs, and bare mud and sand bottoms (Zimmerman et al., 1992). Existing data for Galveston Bay is available through the NMFS Baseline Production Program.

Kneib and Wagner (1994) used flume weirs to investigate the use of intertidal marshes by fish and invertebrates on Sapelo Island, Georgia. The system they used consisted of a series of wooden support posts defining a pentagon-shaped sampling area of 100 m^2 (Kneib and Wagner, 1994). Removable screen panels (1.2 mm square mesh) were inserted between the posts to enclose the sampling area and capture nekton in the marsh. Pits fitted with removable screen baskets were installed at the lower apex of the pentagon to capture nekton as they moved out of the enclosure during the ebbing tide. Nekton were collected from the baskets after the tide receded from the marsh surface. Marsh use during different tidal stages could be assessed by installing the panels at different tidal stages. Kneib (1991) provided details on flume weir construction and operation.

6.5.3 QA/QC Considerations

Population data collected using nets of any form is only comparable if net mesh size and fishing effort are standardized. Gill net, trawl, beach seine, and bag seine data are standardized by catch per unit effort based on the size of the area sampled and fishing time. It is also desirable to standardize sampling by tidal stage and time of day to the extent practicable as most estuarine fish species demonstrate a great deal of tidal and diurnal movement that must be accounted for. Although noise introduced to the data due to these behavioral patterns can be accounted for, a much larger data set will be required to achieve the same level of accuracy in estimates.

Additional Considerations

Consistency in the taxonomic identification of fish can best be achieved through initiating a regional taxonomic program and establishing a reference collection. Regional taxonomic workshops should be conducted on a regular basis (e.g., biennially) with all agencies participating in the Galveston Bay Regional Monitoring Program attending. The TPWD should be responsible for establishing a reference collection including, at a minimum, examples of all species included in their coding system.

The TPWD *Marine Resource Monitoring Operations Manual* describes protocols for data submission and editing that should be followed during all fish sampling conducted as part of the Regional Monitoring Program. The Operations Manual also describes computer data field checks that provide additional quality assurance. Routine equipment checks should be conducted at the beginning and completion of each sampling effort.

6.6 FINFISH COMMERCIAL HARVEST

Although not directly related to any of the Resource Management Objectives, information on the commercial and recreational value of fish and shellfish harvested from Galveston Bay is important for a number of reasons. First it provides the primary means for assessing the economic value of fisheries. Such assessments are important for measuring the costs and benefits of human activities that impact the fisheries. Second, this information allows regulators to evaluate the effect of management actions (e.g., changes in regulations) on the resource. Three species are identified by the Species Population Protection Task Force as indicators of the condition of fish populations in Galveston Bay and whose commercial and recreational harvest should be monitored under the Regional Monitoring Program. These three species are:

- bay anchovy *(Anchoa mitchilli)*
- Atlantic croaker *(Micropogonias undulatus)*
- gulf menhaden *(Brevoortia patronus)*

Bycatch includes all non-target species kept or discarded by fisherman and target species that are discarded. The amount of bycatch taken in Galveston Bay is another concern related to commercial and recreational fisheries and specific management objectives related to bycatch have been identified. Because there are extensive commercial and bait shrimp trawl fisheries operating in Galveston Bay the potential to impact a number of important fisheries exists. In the following discussion, methods are described for monitoring commercial harvests, recreational harvests, and the types and quantities of species taken in the bycatch of commercial and bait shrimp trawlers.

6.6.1 Data Use and Limitations

Monitoring the species and numbers of finfish taken in the bycatch of commercial and bait shrimp trawlers will provide information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-3: Reduce bycatch within the estuary by 50% by the year 2007, accounting for seasonal patterns.

Monitoring commercial and recreational finfish harvests will provide information supporting determinations of whether the following Resource Management Objectives are being met:

SP-1: At a minimum, maintain fish and crustacean populations within 50% of 1975-85 mean levels.
HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

The commercial harvest of finfish in Galveston Bay has been monitored since 1880 providing one of the most long-term data sets describing Bay fisheries available (Osborn et al., 1992). Although inconsistencies in data collection techniques prevent its use for statistical analyses of trends or changes in populations, it does provide valuable information about historical changes in community structure (i.e., the relative abundance of species).

Agency Mandates/Objectives

The TPWD, in conjunction with the National Marine Fisheries Service, monitors the commercial harvest of finfish in Galveston Bay. The objectives of the TPWD program are:

- Determine the live weight and ex-vessel value of finfish, crabs, oysters, shrimp, and other marine life purchased by seafood dealers from commercial fishermen as an indication of harvest (fishing mortality) by commercial fishermen to comply with Texas Parks and Wildlife Department (TPWD) Code (1985-86), Sections 61.051, 66.209, 66.217, 77.004, and 77.005

- Publish results in report form which will assist managers and legislators in effectively managing the coastal fisheries of Texas (TPWD, 1989).

The TPWD Texas Marine Sport Harvest Monitoring Program collects information on recreational fishing throughout Texas. The objectives of that program are:

- Determine estimates of total daylight marine resource landings, catch per unit of effort, and size composition by species for:
  - Bay and Gulf private-boat sport fishermen
  - Bay and Gulf party-boat (10 people or fewer) sport fishermen.

- Publish results in report form which will assist ecosystem and fishery managers in effectively regulating harvest (TPWD, 1993b).

6.6.2 Sampling and Analytical Methods

Existing Monitoring Programs/Special Studies

The TPWD Coastal Resource Harvest Commercial Landings Program monitors commercially harvested finfish, shrimp, crab, oyster, and other marine resources. Licensed seafood dealers are required to report information about all edible saltwater products purchased from commercial fishermen in Monthly Marine Products Reports submitted to TPWD or the National Marine Fisheries Service (NMFS). Data collected includes total weight or number of individuals, price per pound, and the name of the water body where the seafood was collected. Data from this program are stored on magnetic tape in a mainframe computer located in Austin.

The TPWD Coastal Resource Harvest Recreational Landings Program monitors recreational finfish harvests in Galveston Bay. Under this program on-site, trip-end interviews are conducted at 125 boat access survey sites. A total of 133 surveys are conducted each year. Data collected include specifics about the fishing effort of each boat interviewed, the number and species of fish landed, total length of fish landed, species sought, and fishing method.

Galveston Bay National Estuary Program sponsored work by NMFS to characterize bycatch associated with trawl shrimp fisheries in Galveston Bay. To accomplish this NMFS reviewed existing bycatch studies from Galveston Bay and conducted new sampling efforts to characterize the species composition and abundance of bycatch taken throughout the Bay. Historical information was found to be quite limited, consisting of several studies conducted during the 1980s. Furthermore, these studies were limited in their spatial and temporal coverage and frequently focused on a single species or small group of selected species. Martinez et al. (1993) describe three of the most prominent studies and discuss their results.

Twenty-five shrimp vessels (both commercial and bait trawlers) were selected by NMFS to participate in a study of bycatch in Galveston Bay. Nineteen of these 25 were randomly selected to provide samples from their operations for analysis of bycatch. Samples were collected by on-board observers during normal fishing operations and captains were paid up to $200 per sampling trip (Martinez, et al., 1993). Sampling was stratified by dividing the Bay into three fishing zones, Trinity Bay, Upper Galveston and East Bays, and Lower Galveston and West Bays.

Recommended Monitoring Approach

The methods used in the TPWD Coastal Resource Harvest Commercial Landings Program and Coastal Resource Harvest Recreational Landings Program are suitable for monitoring commercial and recreational finfish harvests, respectively. Data from past monitoring conducted under these programs provide valuable historic information that can be used to assess trends in commercial and recreational harvests. These methods should be applied during all commercial or recreational finfish harvest monitoring conducted as part of the Regional Monitoring Program.

Methods for monitoring bycatch in the commercial and bait shrimp trawl industry are described in Martinez et al. (1993). These methods are based on the work conducted by NMFS but may be modified to provide a more complete sampling of all commercial and bait shrimp vessels.

Commercial Harvest

Any individual applying for or renewing a seafood dealers license must indicate whether or not saltwater products will be purchased from commercial fishermen. A list of all license holders is maintained by TPWD. All licensed seafood dealers are to submit a Monthly Marine Products Report (MMPR) to TPWD. The MMPR covers the preceding month's transactions including total weight (or total number of individuals), price per pound, and the name of the water body where the catch was taken. Shrimp landings may either be reported directly to NMFS or by submitting a MMPR to TPWD. Details on the Coastal Resource Harvest Commercial Landings Program methods are contained in the *Commercial Harvest Field Operations Manual* (TPWD, 1989).

Recreational Harvest

The TPWD Coastal Resource Harvest Recreational Landings Program surveys the catch of sport-boat fishing landings throughout Texas. Estimates of fishing pressure are obtained through counts of trailers and empty wet slips at boat access sites. Survey sites are selected randomly but selection is weighted according to mean rove counts, adjusted for trailer location, percent bay and pass pressure, and percent angling parties. Landing rates and size composition of the catch by species are obtained through on-site interviews of boaters completing their trips.

Bycatch

TPWD has recently begun a bycatch monitoring program based on the work by NMFS. It is recommended that bycatch monitoring conducted as part of the Regional Monitoring Program follow the protocols developed for the TPWD monitoring program. The TPWD protocols call for collecting a sample of approximately 25 pounds (4 gallons of sample weighed to the nearest pound) after the total weight of the catch from a commercial shrimp trawl drag is obtained (TPWD, 1994). Samples are only collected from licensed commercial bay shrimp vessels. Samples are returned to a TPWD field station to obtain information on species composition, size, number, and weight.

Martinez et al. (1993) stratified sampling by location and time of year. It is recommended that sampling under the Galveston Bay Regional Monitoring Program be similarly stratified until available data indicates a change in sampling effort is justified. A detailed description of on-board procedures is provided in Appendix 3 of Martinez et al. (1993). Example data sheets for recording bycatch information and sample descriptions are included in Appendix 3 of Martinez et al. (1993).

6.6.3 QA/QC Considerations

A program that relies on public input for data is susceptible to significant error due to inconsistencies in reporting. The amount of error is minimized by providing participants in the program with detailed instructions on data tabulation and reporting procedures. The *Commercial Harvest Field Operations Manual* (TPWD, 1989) provides such instructions. Quality control can best be achieved through spot checks (i.e., boat visits) in which agency personnel conduct separate tabulations for later comparison with data submitted by the seafood dealers. Aerial surveillance could also be used as a means of verifying the location of harvests reported by commercial fishermen.

6.7 OYSTER POPULATION

Oysters are an economically important species in Galveston Bay that has been commercially harvested since the 1800s. Because of their sessile nature, changes in the abundance and distribution of oysters provides an excellent means for assessing environmental conditions in an area. Monitoring oyster populations is important both because of their economic value and their ecological significance.

Monitoring the condition of Galveston Bay oyster populations involves measurement of both the extent of oyster reefs and the density and condition of the oysters themselves. Throughout much of the following discussion these two aspects of monitoring oyster populations are treated separately. The discussion on data use and limitations is applicable to oyster population monitoring as a whole. There are, however, some distinct difference between the sampling and analytical methods and the QA/QC procedures used in measuring the aerial extent of oyster reefs and the density and condition of the oysters themselves.

6.7.1 Data Use and Limitations

Information on the abundance and distribution of oyster populations will be used to determine whether the following Resource Management Objective is being met:

SP-2: At a minimum, maintain oyster population levels within 50% of 1983-1993 levels.

Monitoring oyster populations will also provide information to support a determination of whether the following Resource Management Objective is being met:

FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

6.7.2 Sampling and Analytical Methods

This subsection begins with a brief description of sampling and analytical methods that have been used to measure the aerial extent of oyster reefs and the abundance of oysters in Galveston Bay.

Existing Monitoring Programs

The TPWD is the only agency presently conducting routine monitoring of oyster abundance in Galveston Bay. As part of that agency's Resource Monitoring Program, 30 samples are collected each month using a 495 mm wide by 241 mm high oyster dredge. Sampling sites are selected randomly prior to each sampling event from among 126 areas known to contain oyster reefs.

No agency is presently monitoring the extent of oyster reefs in Galveston Bay. A survey of the location, relief, and areal extent of oyster reefs in Galveston Bay has been sponsored by GBNEP. Seismic survey techniques were used to identify and map the extent of oyster reefs and ground-truthing was conducted (using tong or dredge to collect samples) to verify the presence of oyster reefs (Powell and Soniat, 1991). A global positioning system (GPS) navigational system was used to precisely map the location of reefs and ground-truthing samples.

Recommended Monitoring Approach

Only TPWD presently conducts routine monitoring of oyster population density in Galveston Bay. The methods used by that agency are suitable for assessing attainment of the Resource Management Objectives described above and to meet the general objectives of the Regional Monitoring Plan.

The methods and equipment used by TPWD are described in detail in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a). Samples are collected only from known oyster reefs that are at least 0.2 m higher than the surrounding bay bottom, 91.4 m long, 0.5 m wide, and below the mean low tide line on nautical charts. All oyster shell equal to greater than 25 mm in length should be considered in the sample. If shells of live and dead oysters can be culled (separated) then each should be considered separately in counts. If live and dead oysters can not be culled, then only attached live oysters should be counted. For each sample, 19 live oysters should be randomly selected for measurement and the remainder should be counted. Five individuals should be selected from among the 19 live oysters selected measured and the spat (5-25 mm) on one randomly selected side of each should be counted. Five randomly selected dead shells should be selected and the spat similarly counted.

The acoustic profiling techniques described by Simons et al. (1992) and applied in a GBNEP sponsored survey of oyster reefs in Galveston Bay are recommended to be used to measure the areal extent of oyster reefs for the Regional Monitoring Program. These methods provide accurate and precise mapping of oyster reefs at a relatively low cost. The methods have already been used successfully in Galveston Bay, thus providing base line data for future comparisons. However, it is recommended that the accuracy and precision of mapping efforts be increased by running more transects than during the GBNEP survey.

It is recommended that bathymetric data be standardized to a constant datum and processed for analysis by a Geographic Information System compatible with that used for the Habitat Monitoring component of the Regional Monitoring Program.

Additional Considerations

It may also be desirable to monitor oyster condition and infection of dermo. Methods for measuring dermo infection are described in Ray (1966) and Wilson, et al. (1990). It is recommended that a condition index be developed following the methods of the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program.

Data Reporting

Species abundance data are recorded on Marine Resource Monitoring Data Sheets and ancillary information recorded on Marine Resource/Harvest Investigation Meteorological and Hydrological Data Sheets. Example copies of these data sheets are included in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a). Codes for identifying sampling grid locations, species, sex and age of individuals, and the collection method used are also contained in the Operations Manual.

6.7.3 QA/QC Considerations

The *Marine Resource Monitoring Operations Manual* outlines procedures for data coding, data submission, and specific computer programmed data checks. All oyster population monitoring data recording should follow these procedures and be subject to the described data checks. Routine equipment inspections should be conducted at the outset and upon completion of each sampling event to prevent equipment failure in the field and ensure proper operations.

6.8 FISHERIES LOSSES DUE TO IMPINGEMENT AND ENTRAINMENT

Existing information indicates that significant numbers of fish and crustaceans are lost each year due to impingement and entrainment at water intake structures. In 1978 more than 87 million organisms weighing nearly 450,000 kg were impinged at five Houston Lighting and Power (HL&P) generating stations (Palafox, 1993). A number of commercially and recreationally important species were among those most frequently affected. These include white shrimp *(Penaeus setiferus)*, brown shrimp *(Penaeus aztecus)*, blue crab *(Callinectes sapidus)*, Gulf menhaden *(Brevoortia patronus)*, bay anchovy *(Anchoa mitchilli)*, sand seatrout *(Cynoscion arenarius)*, spotted seatrout *(Leiostomus xanthurus)*, and Atlantic croaker *(Micropogonias undulatus)* (Palafox, 1993).

6.8.1 Data Use and Limitations

Monitoring fisheries losses due to impingement and entrainment at water intake structures provides information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-4: Reduce current levels of fish mortality caused by impingement/entrainment by 50% by the year 2007.

To determine whether this objective is being met the monitoring data must be capable of detecting changes of the indicated magnitude (i.e., 50 percent) in statistical comparisons with existing information. Results from this component of the Regional Monitoring Program should also provide information that could be used in selecting appropriate actions for reducing losses if the objective is not being met.

Agency Mandates/Objectives

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this TNRCC develops water quality standards, and regulates point and nonpoint pollution sources.

The TNRCC is primarily concerned with measuring the physical/chemical characteristics of water for comparison with state standards and criteria and permit limitations. Biological data, however, serve a number of purposes that include identifying appropriate designated uses, assessing water quality standards and criteria, and measuring the ecological impact of changes in water quality. Information on fisheries losses due to impingement and entrainment at water intake structures would assist TNRCC in developing permit restrictions for these structures.

This component of the Regional Monitoring Program should provide information on the affects of water temperature and season on impingement and entrainment rates. Existing information suggests that these factors influence survival and the number of individuals impinged or entrained. Such information could be used to select appropriate management options for reducing mortality due to impingement and entrainment.

6.8.2 Sampling and Analytical Methods

Existing Monitoring Programs

The only agency that presently conducts routine monitoring of impingement and entrainment at water intake facilities is TNRCC. Under the TNRCC program two locations (one power plant and one industrial) are sampled twice each year. Past monitoring has also been conducted by Houston Light and Power (HL&P) at five HL&P cooling structures in the Galveston Bay area.

Recommended Monitoring Approach

The TNRCC/HL&P monitoring program provides the most complete data set available describing fisheries losses due to impingement and entrainment at water intake structures. Because of the existing data and the fact that only TNRCC has established protocols, the methods used in that program are recommended for all impingement and entrainment data collection conducted as part of the Galveston Bay Regional Monitoring Program. These methods are described in detail in the TNRCC Impingement and Entrainment Monitoring Protocols (G. Guillen, TNRCC, personal communication). Results of the fisheries and invertebrate monitoring programs will provide population estimates to be used in evaluating the impacts of impingement and entrainment on selected species.

6.9 INTRODUCED EXOTIC SPECIES

Several introduced exotic species present in the Galveston Bay estuary system threaten to displace native species and reduce habitat quality. Monitoring the abundance and distribution of introduced exotic species is necessary to protect these species and their habitat and to provide managers with the information required to develop workable control plans. The Species Population Protection Task Force selected the following three introduced exotic species to be monitored as part of the Galveston Bay Regional Monitoring Program:

- Grass Carp *(Ctenopharyngodon idella)*
- Nutria *(Myocastor coypu)*
- Fire Ants *(Solenopsis spp.)*

Monitoring populations of each species will require different methods and each is therefore treated separately in the following discussion. Grass carp and fire ant populations will be monitored in conjunction with other components of the Regional Monitoring Program.

6.9.1 Data Use and Limitations

Information on the abundance and distribution of introduced exotic species will be used to determine whether the following Resource Management Objective is being met:

SP-6: By the year 2005 reduce the abundance of selected exotic species, including nutria and grass carp, by 10%.

Results from this component of the Regional Monitoring Program will also support a determination of whether the following Resource Management Objective is being met:

HP-6: Improve and protect habitat on 10 major colonial bird nesting sites within 5 years.

6.9.2 Sampling and Analytical Methods

Existing Monitoring Programs

Grass Carp: Grass carp were introduced to the United States in 1963, primarily to control the growth of aquatic vegetation. In 1967, concerns over possible detrimental effects on ecosystems led the State of Texas to prohibit the introduction of grass carp, however, illegal introductions were reported in the early 1980s. In 1981 the Texas Legislature approved an experimental introduction of triploid (functionally sterile) grass carp (Trimm et al., 1989). Recent evidence suggests that grass carp, originating from either illegal introductions or triploid stockings, have successfully spawned in the Trinity River (Robert Howells, personal communication). Furthermore, samples of juvenile individuals collected at a number of locations in Galveston Bay indicate that successful recruitment has also occurred in the estuary.

Presently there is no routine monitoring of grass carp populations in Galveston Bay. The TPWD sampled ichthyoplankton in the Trinity River to determine whether successful reproduction of grass carp is occurring in the area. Sampling was conducted during the spring and summer of 1992 and 1993 at three locations below Lake Livingston. Samples were collected using a 0.5 m conical plankton net cast from a bridge or boat (Robert Howells, personal communication). In addition, juvenile and adult grass carp have been collected during routine fisheries monitoring and fish kill monitoring conducted by TPWD, and incidentally by sport and commercial fisherman. Grass carp data from these sources are summarized by Trimm et al. (1989).

Nutria: Wild populations of nutria first became established in the United States in the 1940s (Kinler et al., 1987). Populations were kept in check in most areas by trapping due to the heavy demand for their pelts in Europe. However, the market for nutria fur declined dramatically in the 1980s and populations are now increasing in many areas. High densities of nutria can cause damage to agricultural crops, levees and shoreline, and marsh vegetation. Recent surveys in Louisiana identified approximately 12,000 acres of marsh that had been damaged by nutria (Greg Linscombe, personal communication). No routine monitoring of nutria populations is presently conducted in the Galveston Bay estuary.

Fire Ants: Fire ants are thought to have been first introduced to the United States in the early 1900s, possibly in ballast or dunnage discarded from ships (Lofgren, 1986). Despite efforts to control their populations, fire ants now occur throughout much of the southern United States from Texas to Florida and as far north as Tennessee. Fire ants are extremely aggressive, stinging insects with a voracious appetite and high reproductive capacity. They have been found to prey on the eggs and young of a number of bird and reptile species and have caused extensive damage to several agricultural crops. In some instances fire ants are believed to have caused local decreases in populations of prey species (Adams, 1986).

Presently there is no routine monitoring of fire ant populations in the Galveston Bay estuary. The Species Population Protection Task Force is concerned about possible impacts of this species on colonial nesting waterbirds in the area. However, no studies to estimate the extent of impacts from fire ant predation on these populations have been conducted.

Recommended Monitoring Approach

Grass Carp: Data collected under the finfish monitoring component of the Galveston Bay Regional Monitoring Program may provide information for measuring changes in the abundance and distribution of adult grass carp in Galveston Bay. However, grass carp are extremely efficient at avoiding nets and do not respond well to shocking (Robert Howells, personal communication). Conventional methods for estimating their population size would probably meet with little success.

A second concern about this species, whether or not it is successfully reproducing in the estuary, is difficult to address based solely on that type of information. Additional sampling to assess reproductive success and recruitment is necessary. Larval sampling would provide the best, most cost effective means of determining whether a viable population exists, and would also provide information about their reproductive life cycle useful for designing control measures if they become necessary. Data from larval sampling could also be used to generate an index of population size in the future.

To determine whether grass carp are successfully reproducing in the Galveston estuary it is necessary to sample ichthyoplankton for viable eggs and larvae. Samples should be collected using a 0.5 m conical plankton net with 1.0 mm mesh. Because the eggs and larvae of this species are slightly negatively buoyant, samples should be collected with an oblique tow from the near-bottom waters (within 0.25 m of the bottom) to the surface (Robert Howells, personal communication).

After allowing the net to completely drain, the cod-end cup should be emptied into the sample container. The cod-end cup should be reattached to the net, the net rinsed from the outside, and the contents of the cup added to the sample container. Samples should be preserved using a solution of 3 to 5 percent buffered (borax or calcium carbonate to a pH of 6.5-7.5) formalin and labeled (Howells, 1985). Sample jars should be filled to prevent eggs and larvae from being splashed onto the sides of the container during transport.

Samples should be processed as described in Howells (1985). All grass carp eggs and larvae should be identified and counted. Descriptions of grass carp larvae are provided in Kilambi and Zdinak (1981) and Conner et al. (undated).

Nutria: Monitoring the size of nutria populations over any large area is difficult due to the habitat these animals are found in and their behavior (Greg Linscombe, personal communication). Nutria have a small home range and their densities fluctuate greatly depending on habitat type (Kinler et al., 1987). Mark and recapture methods are therefore only useful for small areas where relatively continuous habitat conditions exist. It is recommended that population monitoring focus on tracking changes in the relative abundance of nutria by developing an index based on some measure of their activity in selected areas.

Except during periods of extreme cold, nutria are most active at night (Kinler et al., 1987; Dwight LeBlanc, personal communication). Changes in their relative abundance could be monitored using transect or point count methods by spotlighting at night, perhaps in conjunction with alligator surveys. However, in areas of dense vegetation, visual counts would be extremely difficult and could provide inconclusive or misleading data. Alternatively, an index could be established based on some other indicator of their activity such as scat counts, active trail counts, or evidence of feeding activity (Kinler et al., 1987). It is recommended that a special study be undertaken to determine which of these methods would be best suited for the Galveston Bay estuary.

If number of individuals is used as the measure of nutria activity it is recommended that transects or counting stations be located between 1.5 and 2 km apart. It is suggested that transect width and/or the area to be censused at counting stations be determined based on the maximum range of sight in the densest cover to be monitored. Counting time at each station or speed along the transects should be standardized. For other measures of nutria activity (e.g., scat counts, active trail counts, or evidence of feeding activity) it is recommended that sampling be done along established transects (2 km apart). It is recommended that specific criteria for counting any measure other than number of individuals be established (e.g., for determining whether a trail is active).

Fire Ants: A major concern surrounding the abundance and distribution of fire ants centers around their impact on colonial nesting waterbirds. Monitoring of this group, therefore, should be done in conjunction with the colonial waterbird nesting habitat component of the Regional Monitoring Program.

Two methods can be used to determine the extent of the impact of fire ants on colonial nesting waterbirds. It is recommended that their abundance and distribution be monitored by counts of their mounds in the vicinity of waterbird nesting colonies. Mounds should be counted annually prior to the nesting season during colonial waterbird nesting habitat surveys. It is also recommended that the impact of fire ants on these colonies be estimated by surveys for the carcasses of juveniles and eggs preyed upon by the fire ants. These surveys should be conducted at selected nesting colonies at the end of the nesting season.

Available Alternative Monitoring Approaches

Grass Carp: Grass carp spawn during a narrow temperature range (18-20° C) and demonstrate rapid development until hatching (approximately 24 hours) and through the yolk sac stage (24-36 hours) (Robert Howells, personal communication). During early development the eggs and larvae move with the current down stream from the spawning area. Frequent sampling should be conducted during the period when spawning and early development are likely to be occurring (i.e., when water temperatures are near 18-20° C). Several stations should be sampled in areas where spawning is likely to occur and downstream of these locations. Although 0.5 m plankton nets are suitable for collecting grass carp eggs and early larval stages, individuals larger than 12 mm are collected less frequently by this method and may be able to avoid the net (Robert Howells, personal communication). Bongo nets are designed to reduce net avoidance by eliminating the need for a harness that extends in front of the net. These nets consist of paired conical plankton nets that are rigged adjacent to one another by a rigid frame. A single line is attached between the two nets and weighted at its bottom allowing the net to be fished at any selected depth without the need for harnesses extending in front of the mouth of the nets.

Nutria: Rather than monitoring changes in nutria populations it may be desirable to focus on monitoring the extent of nutria damage in marshes surrounding Galveston Bay. Such an approach has been used successfully for monitoring marshes in Louisiana by the Louisiana Department of Wildlife and Fisheries (Greg Linscombe, personal communication). Six-hundred miles of transects are flown by helicopter and the positions of damaged areas are fixed using a global positioning system (GPS). On-site surveys are made to assess the severity of the damage. Damage is classified in one of three categories, heavy feeding, moderate damage, or heavy damage. In May and December of 1993 marsh damage surveys were conducted as part of the Barataria-Terrebonne National Estuary Program in Louisiana.

6.9.3 QA/QC Considerations

Grass carp eggs and larvae can be difficult to identify and are similar to other native species occurring in the Galveston estuary in many respects. Samples should be sent to Heart of the Hills Fisheries Research Station or the Larval Fish Laboratory, Colorado State University for verification.

6.10 THREATENED AND ENDANGERED SPECIES

A number of Federally listed threatened or endangered species occur in the Galveston Bay estuary. Because of the additional protection afforded these species under the Federal Endangered Species Act, information on their abundance and distribution is particularly important to regulators. Species whose populations are in danger of extinction due to human activities are valuable indicators of environmental condition. Management actions taken to protect threatened or endangered species or their habitat are easily evaluated by changes in species abundance.

The Species Population Protection Task Force identified the following species as indicators for threatened and endangered species in Galveston Bay:

- brown pelican
- southeastern snowy plover
- Kemp's Ridley sea turtle
- Texas diamondback terrapin

Although the bird population monitoring described in Section 6.3 will likely provide some data on brown pelican and southeastern snowy plover populations, additional sampling of these species is recommended. Similar methods could be used to census either of these species and suggested methods are therefore described jointly (i.e., bird populations). Monitoring Kemp's Ridley sea turtle and Texas diamondback terrapin populations require different methods and each is treated separately in the following discussion.

6.10.1 Data Use and Limitations

Information on the abundance and distribution of threatened and endangered species will be used to determine whether the following Resource Management Objective is being met:

SP-5: Increase populations of endangered and threatened species.

Agency Mandates/Objectives

The Endangered Species Act provides protection for species that are in danger of extinction over all or a significant portion of their range or are likely to become so within the foreseeable future. Section 9 of the Act makes it unlawful for any person subject to the jurisdiction of the United States to take, import, export, possess, sell, deliver, carry, transport, or ship any listed species. "Take" includes harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, collecting, or attempting to collect. Furthermore, Section 4 of the Act requires the National Marine Fisheries Service (NMFS) or the U.S. Fish and Wildlife Service to develop Recovery Plans for all listed species. Monitoring the abundance and distribution of threatened and endangered species provides information that will be helpful in making decisions regarding the listing or delisting of species.

6.10.2 Sampling and Analytical Methods

Existing Monitoring Programs

Kemp's Ridley sea turtle: Presently there is very little organized monitoring of sea turtles along the Texas coast and most records have probably resulted from opportunistic sightings rather than organized sampling (Charles Caillouet, personal communication). Surveys to locate stranded sea turtles along the southeast coast of the United States are conducted by the Sea Turtle Stranding and Salvage Network (STSSN). These surveys represent the only ongoing, long-term effort to monitor sea turtle populations along the Texas coast. The NMFS Southeast Fisheries Science Center, Galveston Laboratory maintains records of strandings, sightings, and incidental catches of shrimp trawls and hook and line fisheries (Manzella and Williams, 1992). Efforts have been made to increase public reporting of sea turtle sightings by placing signs describing various sea turtle species and providing contact information.

Texas A&M University and NMFS have recently begun a tagging study in Galveston Bay to investigate the impact of dredging activities on the Kemp's Ridley sea turtle. Up to 20 individuals will be tagged with radio (12) or satellite (8) tags so that their movements along the Texas coast can be tracked. In addition, Texas A&M University will establish sea turtle capture/monitoring stations at three locations along the coast, including Bolivar Roads. Pilot studies to determine the population status of Kemp's Ridley sea turtle in these areas will also be initiated (Andre Landry, personal communication).

Texas diamondback terrapin: A public information and reporting system has recently been established for reporting the occurrence of Texas diamondback terrapin in crab traps. Efforts to encourage the public to use crab trapping methods that are less likely to impact terrapin have also begun. Prior to these efforts there was no monitoring of Texas diamondback terrapin abundance or distribution in Galveston Bay.

Bird populations: Three existing monitoring programs that census bird populations in the Galveston Bay estuary are described in Section 6.3. In addition to these programs, the National Audubon Society conducts an annual Christmas Bird Count (CBC) in the area. The CBC tallies all birds within a 24-km diameter area by species at five areas surrounding the Galveston Bay estuary. Four of these count areas (Bolivar Peninsula, Galveston, Houston, and Old River) have been censused on a nearly continuous basis since 1965 (Slack et al., 1992). The fifth count area (Armand Bayou) has been censused since 1982. Slack et al. (1992) found that the brown pelican was frequently reported in the CBC and feel that the data would be suitable for analysis of trends in that species.

None of the existing monitoring programs recorded southeastern snowy plover frequently enough to provide reliable population estimates for that species.

Recommended Monitoring Approach

Kemp's Ridley sea turtle: Due to their low population levels and migratory nature, quantitative measures of Kemp's Ridley sea turtle abundance and distribution would require extensive sampling. The methods used by the STSSN to collect information on sea turtles could provide useful information on the occurrence of Kemp's Ridley sea turtle in Galveston Bay. In the long term such monitoring would provide an index of relative population size. Information about the distribution of Kemp's Ridley sea turtle within the Galveston Bay estuary will allow managers to identify high use areas and see that these areas are protected from human impacts.

It is recommended that a program be initiated to increase public awareness and knowledge of sea turtles and thereby increase public reporting of stranded turtles throughout the Galveston Bay estuary. Information displays could be constructed at public access points in areas were stranded sea turtles have most frequently been observed (e.g., based on Manzella and Williams, 1992). Such displays would encourage public participation and increase awareness. Visitors could be requested to provide information about the amount of time they spent in an area, any turtles observed, and other pertinent information.

It is recommended that information about public use patterns in the vicinity of displays also be collected. This will enable investigators to assess whether changes in the number of reportings are due to changes in sea turtle distributions or to changes in the level of human activity in an area.

Texas diamondback terrapin: It is recommended that a public reporting program be initiated to provide information on the number of Texas diamondback terrapin occurring in crab traps. Although this information could not be used to generate an estimate population size, it would provide an index of population size and could also provide valuable information on the significance of the impact crab trapping is having on terrapin populations.

Reporting cards could be made available at boat launches and public access areas. It is recommended that a display describing the Texas diamondback terrapin and its ecology along with instructions for filling out reports be provided. The display should stress the importance of filling out and submitting the report cards regardless of whether terrapin were caught. Table 6.6 lists suggested information to be requested in the volunteer reporting program.

Table 6-6. TERRAPIN REPORTING INFORMATION

Date
Fishing location
Number of traps
Time fishing was begun
Time fishing ended
Total fishing time (hours)
Approximate time each trap was fished before being checked (hours)
Number of Texas diamondback terrapin caught
Type of bait

Bird populations: It is recommended that brown pelicans and southeastern snowy plover be censused using the point count method. Point counts are conducted by visiting a designated point and counting, either through direct counts or call counts, the number of species and individuals observed within a specified time period. To generate an accurate estimate of population size using this method individuals must be randomly distributed within the defined habitat and the area being censused must be representative of that habitat as a whole. An estimate of the aerial extent of a species habitat must also be available to estimate population size using this method. Without a measure of the total extent of habitat, this method provides an index of population size that can be used for estimating relative changes in a population.

It is recommended that sampling points for brown pelican and southeastern snowy plover be established at known high use areas for these species. Existing or proposed sampling locations for the Shorebird Surveys, Texas Colonial Waterbird Counts (see Section 6.3), or the CBC, should be considered as sampling locations. It is recommended that sampling be conducted during morning low tides of the spring tide cycle each month that sampling is conducted. As both of these species are migratory with regard to there use of Galveston Bay it is suggested that efforts be focused on establishing an index to track relative changes in population size rather than providing an estimate of population size.

Available Alternative Monitoring Approaches

Kemp's Ridley sea turtle: Intensive studies could be conducted using telemetry to track the movement of individual turtles in the Estuary. It is recommended that any such work follow the methods being used in the joint Texas A&M University and NMFS study. Turtles can be captured using entanglement nets or standard bait casting nets deployed along the jetties and in other areas where sea turtles are known to occur in Galveston Bay. Radio tagging of captured individuals will allow their movements to be tracked throughout Galveston Bay.

It is recommended that tagging only be undertaken if results of the Texas A&M University-NMFS study indicate that such methods could provide data suitable for estimating population size. Although useful information about the movement of Kemp's Ridley sea turtles in Galveston Bay could be gained through a limited tagging program, estimating population size would require a significantly greater effort. The potential for harming individuals needs to be carefully considered before subjecting an endangered species to such an intensive sampling program.

6.10.3 QA/QC Considerations

Kemp's Ridley sea turtle: In public access areas where permanent employees are stationed, training/orientation should be provided so that these employees are able to confirm reported sightings.

CHAPTER 7
PUBLIC HEALTH

The Galveston Bay estuary is the largest source of seafood in Texas, and one of the major oyster producing areas in the country. Commercial and recreational fishing represents an almost one-billion dollar industry, and molluscan shellfish (e.g., oysters) and other seafood (e.g., crabs, shrimp, and finfish) harvested from Galveston Bay are consumed by millions of individuals. Maintenance of adequate public health standards of estuarine seafood is essential for the protection of the consuming public, and is critical for the long-term stability of seafood-derived industries within Texas.

Consumption of bioaccumulated toxicants and bacterial pathogens in fish and shellfish tissue and contact with bacterial pathogens during water-based recreational activities are the three major public health concerns associated with the environmental management of Galveston Bay. Because oysters are often eaten raw, contaminated oysters can threaten human health because they are often eaten raw, contaminated oysters have the potential to pose a serious threat to human health. Consumption of other fish, in which toxic contaminants have bioaccumulated can also lead to adverse health effects for the consumer. Contact and non-contact recreational activities in contaminated waters (e.g., swimming, boating) can also present hazards to human health.

Three Resource Management Objectives have been developed in the Galveston Bay Plan to support public health protection:

PH-1: By the year 2000, reduce the risk of consumption of Galveston Bay seafood containing tissue concentrations of toxic substances above risk level standards established by the Texas Department of Health (TDH).

PH-2: Increase the oyster reef areas open to harvest by 25 percent on a spatial and temporal basis by August 1995, as compared to a 1988 baseline.

PH-3: By the year 2000, establish a contact recreation advisory program in all areas of the estuary commonly used for contact recreation.

Monitoring of levels of fecal coliforms in Galveston Bay waters and concentrations of contaminants in the edible tissue of target fish and shellfish are necessary to fulfill these monitoring objectives.

7.1 PATHOGENS

It is not possible to routinely identify and enumerate the many different human pathogens that can be found in estuarine waters. Thus, indicator groups have been used to monitor health risks. In the past, total coliform bacteria, and more recently, fecal coliforms have been used as indicator organisms.

Other microbiological organisms, including *Escherichia coli* (*E. coli*), fecal streptococcus, and enterococcus have been used or recommended as indicators in either USEPA guidance or state water quality standards (Jensen and Su, 1992). However, the Texas water quality criteria for contact and non-contact recreational waters, and the water quality criteria for shellfish growing waters, as defined by the National Shellfish Sanitation Program (NSSP) use only fecal coliform bacteria as indicators.

7.1.1 Data Use and Limitations

The assessment of pathogen contamination is an essential component of a monitoring program concerned with risks to human health and economic viability of an estuary. Monitoring of fecal coliform concentrations provides essential information relating the temporal and spatial distribution of pathogens to regulatory actions, such as issuing contact health advisories and closing shellfish growing areas to harvesting. Furthermore, monitoring of effluent discharges can be used to identify potential sources of pathogens and to support the attainment of water quality standards.

Although fecal coliform monitoring methods have been widely accepted for many years by public health authorities, it is by no means an ideal indicator. One major limitation of the test is that it is subject to many false positive results (that is, it may indicate that a health risk exists when one does not exist). On the other hand, the test does not directly measure several of the naturally occurring pathogens, such as *E. coli* and *Vibrio vulnificus*, which may be harmful if contacted or consumed.

Monitoring of fecal coliform levels in Galveston Bay will provide data to support the determination of whether the following Resource Management Objectives are being attained:

PH-2: Increase the oyster reef areas open to harvest by 25 percent on a spatial and temporal basis by August 1995, as compared to a 1988 baseline.

PH-3: By the year 2000, establish a contact recreation advisory program in all areas of the estuary commonly used for contact recreation.

Agency Mandates/Objectives

With respect to the human health consequences of seafood processing and consumption, the TDH's Division of Shellfish Sanitation Control (DSSC) is responsible for monitoring and harvesting activities within the State of Texas under Chapter 436 of the Texas Health and Safety Code (Hadden and Riggin, 1993). The chapter authorizes the DSSC to monitor and ensure the public safety of fish and shrimp, shellfish (oysters, mussels, and clams), and crabs taken from Texas water for human consumption. The current DSSC monitoring procedures follow the *National Shellfish Sanitation Program Manual of Operations*, published by the Shellfish Sanitation Branch of the U.S. Food and Drug Administration (USFDA and ISSC, 1990).

In part, the procedures require a sanitary survey and classification as to the suitability of the areas to produce shellfish fit for human consumption. The sanitary survey consists of three components:

- a survey of the shoreline to evaluate all actual and potential pollution sources
- an evaluation of hydrographic (water dynamics, dispersion) and meteorlogical (quantity and frequency of rains, effects of winds) effects
- the collection and analysis of water samples for fecal coliform concentrations.

All three components are used to determine the status of harvest areas as either approved, conditionally approved, or prohibited for harvesting. The most variable parameters are rainfall, river flow, and coliform count. Rainfall and river stage are collected daily from the National Weather Service. Fecal coliform concentrations are estimated from water samples collected by TDH from about 112 sampling stations throughout the bay, each one of which is monitored 12 to 30 times a year (Jensen and Su, 1993).

Bacteriological monitoring, using fecal coliform counts, is also performed by the TNRCC, as part of its responsibility for protecting the quality of the state's surface water and groundwater resources. A wide suite of parameters are measured in conjunction with the coliform concentration estimates to monitor ambient water and sediment conditions. Each year, approximately 240 samples are collected by the TNRCC from 68 stations for coliform and other physical and chemical analyses.

Bay waters are deemed unacceptable for recreational use if fecal coliform concentrations exceed USEPA and State of Texas water quality critera of 200 colonies/100 mL for contact recreation and 2000 colonies/100 mL for noncontact recreation. However, no contact recreation advisory program is currently in place within the bay.

7.1.2 Sampling and Analytical Methods

Collection methods

Collection of near-surface water samples is a straightforward procedure that can be performed with hand-held glass or plastic containers. Procedures that are used by TDH and TNRCC differ mainly in the location and timing of the collections. TDH, charged with the protection of public health, is concerned with forming "a profile for periods defining adverse pollution conditions that reflect adverse meteorological, hydrographic, seasonal, and point sources of pollution," (USFDA and ISSC, 1990). TNRCC monitoring data is used, in part, to assess long-term trends in water quality, and thus are concerned with ambient conditions, and not potential worse-case conditions.

Procedures followed by TDH are outlined in:

> *National Shellfish Sanitation Program Manual of Operations.*
> USFDA and ISSC, 1990.

This manual specifies that: *Recommended Procedures for the Examination of Seawater and Shellfish.* (APHA, 1970) shall be followed for the collection, transportation, and examination of samples of shellfish and shellfish waters. Methods and techniques described are reported to be identical to those of *Standard Methods for the Examination of Water and Wastewater, 18th ed.* (APHA, 1992).

Ancillary data collected during field sampling includes water, temperature, dissolved oxygen concentration, and salinity. Observations of weather conditions (air temperature, wind direction and speed) are recorded as well. Rainfall data and river stage information for the Trinity River are updated daily. Based on statistical analyses of historical studies, the TDH uses this data to determine if closures of specific areas are to be made (Hadden and Riggin, 1993).

TNRCC sample collection protocols for bacterial determinations are defined in the *Texas Surface Water Quality Standards*, Section 307.9 (15 TexReg 7495). Again, procedures for the collection and preservation of samples are required to be in accordance with *Standard Methods.*

Analytical methods

Both TDH and TNRCC stipulate the same reference, *Standard Methods*, but different analytical procedures to determine fecal coliform counts. The multiple-tube most probable number test (MPN) is performed by the THDH, as required by the NNSSP. The membrane filter (MF) method is used by the TNRCC. Complete details of the two laboratory test procedures are found in *Standard Methods* (APHA, 1992) and a concise summary of each is presented in Appendix B of Jensen and Su (1992).

While Standard Methods indicates the two procedures produce equivalent results, TDH follow the NSSP requirement to use the MPN procedure. This requirement resulted from NSSP comparisons of the two methods that found the MF procedure yields lower colony counts in turbid water. Apparently high suspended solids content can reduce the ability of the growth media to reach bacteria that would otherwise become countable colonies (Jensen and Su, 1992).

Recommended Monitoring Method

Both methods are required to provide the necessary data to assess the two Resource Management Objectives. The TDH MPN method is required by state and federal regulations, the TNRCC method using the membrane filter method will continue to be used to as an ambient monitoring method to support Galveston Bay Regional Monitoring Program. Although TNRCC results cannot be used directly to supplement NSSP monitoring requirements, both datasets can be used for monitoring the status and trends of fecal coliform bacteria within the bay.

Alternative Monitoring Approaches

In the case of human health protection monitoring, alternative approaches focus on different indicator species than alternative methods of collection or analysis. The use of other indicators of human pathogens have been studied extensively and a brief description of the characteristics of two candidate bacteria are discussed.

E. coli is a member of the coliform bacteria population that may be used to indicate fecal sources. It is a normal and dominant inhabitant of the mammalian digestive tract. However, the use of *E. coli* as an indicator organism is somewhat hampered by the facts that it is not a single species; it can be found outside the human intestinal tract; other organisms found in water that do not represent fecal pollution possess some of the attributes of *E. coli*; and identical genera are found in human and other animal intestinal tracts (Jensen and Su, 1992).

Enterococci belong within the fecal streptococcus group, whose normal habitat is the gastrointestinal tract of warm-blooded animals, and their presence in surface waters is an indication of fecal contamination. Studies at marine and fresh water bathing beaches indicated that swimming-associated gastroenteritis was directly related to the quality of the bathing water and that enterococci were the most efficient bacterial indicator of water quality (Cabelli et al., 1982). USEPA recommends enterococci as the only bacterial indicator for marine water in its *1986 Water Quality Criteria* (USEPA, 1986b).

Both of these bacteria possess some advantages over fecal coliforms as indicator organisms. But the regulatory mandates of the TDH to follow procedures described in the NSSP effectively prevent changes in methods. Therefore, for the foreseeable future, the fecal coliform group is likely to continue to be the basis for much of the water quality testing and regulatory decision making regarding both shellfish harvesting and contact recreation. However, members of the GBNEP Public Health Task Force have strongly recommended that the use of other bacteriological indicators (e.g., enterococcus, *E. coli*) be considered for inclusion into the regional monitoring program at a later date.

7.1.3 QA/QC Considerations

TDH guidelines require that samples be collected, transported, and analyzed in accordance with standard methods as found in the following documents:

Standard Methods for the Examination of Water and Wastewater, 16th ed. Washington, DC. American Public Health Association, American Water Works Association, Water Pollution Control Federation; 1985. (The latest edition is the 18th, published in 1992).

Bacteriological Analytical Manual of the Division of Microbiology, Center for Food Safety and Applied Nutrition, 6th ed. Washington, DC. US Food and Drug Administration, 1984.

Official Methods of Analysis of the Association of Official Analytical Chemists, 14th ed. Arlington, VA. Association of Official Analytical Chemists, 1984.

The NSSP further specifies that the state shellfish control agency (TDH, in this case):

a. Provide an internal monitoring program to evaluate laboratory facilities, equipment, and materials

b. Participate in FDA-sponsored proficiency testing programs and on-site laboratory evaluations.

c. Provide proper training and supervision for laboratory personnel.

d. Maintain records of analytical performance, analytical results, and equipment operations and maintenance.

f. Evaluate laboratories supporting state shellfish programs pursuant to established NSSP guidelines.

TNRCC has established QA procedures for the entire range of sampling and analytical efforts conducted by the agency. For example, all sample collection is required to be conducted according to procedures found in the latest edition of:

Standard Methods (APHA, 1992), or

Methods for the Chemical Analysis of Water and Wastes. 3rd Ed. EPA 600/4-79-020. Washington, DC. US Environmental Protection Agency, 1983, or

Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. Washington, DC. US Environmental Protection Agency, 1973.

Sample handling procedures, and physical, chemical, and microbiological analytical procedures for effluents are required to meet the specifications of *Standard Methods* and the regulations published in 40 Code of Federal Regulations Part 136, pursuant to the Federal Water Pollution Control Act. Required interlaboratory quality control practices are as recommended in the latest edition of the manual:

> *Handbook for Analytical Quality Control in Water and Wastewater Laboratories*. EPA 600/4-79-019. Cincinnati, OH. US Environmental Protection Agency, 1979.

7.2 TOXIC CONTAMINANTS

Contamination of aquatic resources by toxic chemicals is a well-recognized problem. Each year, millions of pounds of fish and shellfish, caught by commercial and sport fishermen in Galveston Bay are consumed. However, little or no testing of edible tissues for toxic contamination by heavy metals, organic pollutants, and pesticides has been conducted to assess or monitor public health risks resulting from bioaccumulation (Brooks et al., 1992).

Toxic contamination and bioaccumulation monitoring can provide data to directly support and monitor the attainment of the Public Health Resource Management Objective as stated below:

> PH-1: By the year 2000, reduce the risk of consumption of Galveston Bay seafood containing tissue concentrations of toxic substances above risk level standards established by the Texas Department of Health (TDH).

The regulatory framework for ensuring that fish are safe to eat is similar to that for oysters. Testing procedures are governed exclusively by state laws. At present, there are no FDA regulations addressing pollution levels for fish consumption. In Texas, as for shellfish, the DSSC oversees human health aspects of the consumption and processing of fish under Chapter 436 of the Texas Health and Safety Code (Hadden and Riggin, 1993).

7.2.1 Data Use and Limitations

Health problems and regulation of fish differ in significant ways from bacteriological contamination of oysters. With the exception of fish that have not been properly stored, the human health consequences from eating contaminated fish are usually long-term and subtle, in contrast to the immediate effects of eating bad oysters. Fish are mobile, while oysters are immobile. Thus, while the safety of oyster consumption can be indicated by sampling the surrounding waters, the same is not true for fish. As well as having to test the tissue of the fish itself, it is also necessary to test for a wide suite of possible contaminants. To add to the complexity, a number of fish and a number of different species of fish must be tested before reasonable decisions can be made as to the safety of a species for human consumption.

No routine ambient monitoring of toxic contaminant levels in fish tissue is presently being carried out in Galveston Bay. TNRCC and TDH do collect and sample tissue on an episodic basis, in response to oil spills, toxic leaks, and other accidental releases into the bay, although the focus of each agency is different. TNRCC's effort is in support of water quality monitoring, while the primary concern of TDH is human health risk. Part of the reason for the lack of routine monitoring is the cost associated with tissue analyses, which can range from $1,200 to $2,500 per sample, depending on the suite of parameters tested.

NOAA's Status and Trends Mussel Watch Program is designed to monitor the current status and long-term trends of selected environmental organic and trace metal contaminants along the Atlantic, Pacific, and Gulf coasts of the U.S. by measuring the concentrations of these contaminants in bivalves. Six sites within Galveston Bay are sampled every two years. The data from this program is designed to monitor large-scale trends throughout the nation and is too sparse to provide detailed information on ambient conditions within Galveston Bay.

7.2.2 Sampling and Analytical Methods

Tissues are sampled for a variety of reasons, including the assessment of human health risk and the investigation of pollution sources. However, tissue sampling and analysis are costly and time consuming, and decisions based on these data can have significant impacts on different sectors of society. For these reasons it is important to maximize the comparability of data derived from tissue analysis by strictly following sampling guidelines for every sampling event (DSSC, no date). These guidelines should be made available to all agencies and organizations that may be involved in tissue sampling efforts, whether for human health concerns or species propagation and health studies. Both TDH and TNRCC have existing and similar protocols for tissue collection and preparation (DSSC, no date; TWC, 1993).

Recommended Methods

The TDH protocols, *Tissue Sampling Guidelines* (DSSC, no date), are specifically designed for the sampling of edible tissues and so are recommended to be used for monitoring efforts focusing on human health issues.

Table 7-1 lists those indicator species recommended by the Public Health Protection Task Force members.

As discussed above, TDH laboratories perform (or supervise contract laboratories) all the analyses for toxic contaminants in fish and shellfish tissue for samples collected in Galveston Bay. The continued use of these existing laboratory methods is recommended to support the public health Resource Management Objectives.

Table 7-1. RECOMMENDED INDICATOR SPECIES FOR PUBLIC HEALTH PROTECTION

Shellfish
Blue crab
Oyster
Fish
Black Drum
Southern Flounder
Atlantic Craoker
Seatrout
Redfish

USEPA-recommended analytical methods are used for all tissue analyses. For determinations of trace metal concentrations, the references used are:

Methods for the Determinations of Metals in Environmental Samples. EPA 600-4-91-010. Cincinnati, OH. US Environmental Protection Agency, 1991.

Methods for the Chemical Analysis of Water and Wastes 3rd ed. EPA 600/4-79-020. Cincinnati, OH. US Environmental Protection Agency, 1983.

For specific metals, the following methods are used (S. Dubois, 1994):

Preparation and digestion	200.3 (for all except mercury)
Mercury	245.6
Arsenic	206.3 (hydride method)
Cobalt and zinc	200.7 (using ICP-inductively coupled plasma spectroscopy)
Lead	239.2 (graphite furnace).

USEPA has published interim procedures for sampling and analysis of priority pollutants in fish tissue (USEPA, 1981); however, official USEPA-approved methods are available only for the analysis of low parts-per-million concentrations of metals in fish and shellfish tissue (USEPA, 1991b).

Alternative Methods

It is recommended that the fish sampling and analysis guidance presented in *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (USEPA, 1993b) be incorporated in the tissue collection and preparation protocols issued by TDH. The advantage of more detailed and more rigorous QA/QC methods will enhance the quality and comparability of data, especially when collected by staff from different agencies.

7.2.3 QA/QC Considerations

QA procedures sample collection and preparation are documented in the DSSC sampling guidelines (DSSC, no date). The majority of EPA-approved analytical methods include method-specific QA procedures. For overall laboratory QA/QC procedures, TDH follow EPA guidelines described in:

> *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* QAMS-005/80. Washington, DC. US Environmental Protection Agency, 1980.

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Appendix B

Thematic Layer Name- LandCover_TM

Thematic Layer Description- LandCover_TM is a Landsat Thematic Mapper (TM) based Land cover/Land use classification developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal-Change Analyses Program (C-CAP) and modified by the Texas Parks and Wildlife Department (TPWD). The classification system is a hierarchical system combining characteristics from the National Wetland Inventory system (Cowardin *et al.*, 1979) and the Anderson Land cover/Land use system (Anderson *et al.,* 1976) customized for satellite derived data.

Data Structure-

Field	Defined	Type	Length
1	Name	C	25
2	Division	I	3
3	Super-Class	I	3
4	Class	I	3
5	Sub Class	I	3

The Field 1 character string corresponds to the Land Cover Type (i.e. UPLANDS, Urban Woodlands, etc.). The integer value in remaining fields are the Class Number.

Attribute Descriptions- LandCover_TM is structured as follows:

X	**DIVISION**
X.X	<u>Super Class</u>
X.XX	Class
X.XXX	Sub Class

C-CAP/TPWD Coastal Land Cover Classification System

CLASS NUMBER	LAND COVER TYPE
1	1.0 **UPLANDS**
2	1.1 <u>Developed Lands</u>
3	1.11 High Intensity
4	1.12 Low Intensity
81	1.13 Urban Woodlands
5	1.2 <u>Cultivated Lands</u>
6	1.21 Croplands (Active, vegetated)
7	1.22 Agricultural wetlands (Rice Fields)
8	1.23 Fallow crop lands
9	1.3 <u>Grasslands</u>
10	1.31 Managed pastures

11 1.32 Prairie

12 1.4 Woody Lands (Shrub-Scrub/Forested)
13 1.41 Deciduous
14 1.42 Evergreen
15 1.43 Mixed

16 1.5 Bare Lands
17 1.51 Unvegetated non-saline lands
18 1.52 Levees and Spoil Deposition

19 2.0 **WETLANDS** (Defined to exclude Bottoms, Reefs, Nonpersistent Emergent Wetlands, and Aquatic Beds, all of which are covered under 3.0, Water and Submerged Land)

21 2.2 Marine/Estuarine Unconsolidated Shore (Beach, Flat, Bar)
23 2.22 Sand (Salt and Sand Flats)
24 2.23 Mud/organic Flats
25 2.24 Algal Flats

26 2.3 Estuarine Emergent Wetland
27 2.31 Haline (Salt Marsh)
28 2.311 Low Salt Marsh
29 2.312 High Salt Marsh
30 2.32 Mixohaline (Brackish March)
31 2.321 Low Brackish Marsh
32 2.322 High Brackish Marsh
33 2.33 Oligohaline (Intermediate March)
34 2.331 Low Intermediate Marsh
35 2.332 High Intermediate Marsh
36 2.34 Salt Prairie

37 2.4 Estuarine Woody Wetland (Shrub-Scrub/Forest)
38 2.41 Deciduous
39 2.42 Evergreen
40 2.43 Mixed

49 2.7 Palustrine Unconsolidated Shore (Beach, Flat, Bar)
51 2.72 Sand
52 2.73 Mud/Organic
53 2.8 Palustrine Emergent Wetland
54 2.81 Permanent
55 2.82 Wet Prairie

56 2.9 Palustrine Woody Wetland (Shrub-Scrub/Forested)
57 2.91 Bottom land/Riparian Woodland
58 2.92 Swamps Cypress-Tupelo
59 2.93 Deciduous Shrub-Scrub (Tallow-Baccharis)

60	3.0 **WATER AND SUBMERGED LAND** (Defined to include wetland deep water habitats with surface water but lacking trees, shrubs, and emergent vegetation)
61	3.1 Water (Bottoms and undetectable reefs, aquatic beds nonpersistent emergent wetlands
82	3.10 Shallow Water
67	3.2 Marine/Estuarine Aquatic Bed
69	3.32 Rooted Vascular (e.g. seagrass)
70	3.321 Dense Beds
71	3.322 Sparse Beds

* Mapping resolution is based on 28 meter pixels. Minimum mapping unit is .4 ha. Italicized **Class Number** values represent classes developed through interpretation of aerial photography and produced at a scale of 1:24,000.

TEXAS PARKS AND WILDLIFE DEPARTMENT C-CAP LAND COVER DESCRIPTIONS (modified from "NOAA COAST WATCH CHANGE ANALYSIS PROJECT GUIDANCE FOR REGIONAL IMPLEMENTATION" Ver. 1.0).

NAME, CLASS
DESCRIPTION

1.0 UPLANDS, Class #1
The Uplands division consists of five super-classes: Developed lands, Cultivated Lands, Grasslands, Woody Lands and Bare Lands. Upland classes are adapted from Level I classes in the USGS Land Use/Land Cover Classification System (Anderson *et. al.,* 1976). Refined through manual delineation of imagery.

1.1 Developed Lands, Class #2
Includes areas of intensive anthropogenic use. Much of the land is covered by structures and impervious surfaces.
1.11 High Intensity Developed Land, Class #3, contains little or no vegetation. This includes industrial sites, large buildings, interstate.
1.12 Low Intensity Developed Land, Class #4, contains mixes of structures, bare lands and vegetated lands. Typically suburban settings.
1.13 Urban Woodlands, Class #81, contains mixes of domesticated woodlands and ornamentals largely influenced by woody vegetation within suburban landscapes.

1.2 Cultivated Lands, Class #5
Includes herbaceous croplands, rice fields and fallow fields. Seasonal spectral signatures, geometric field patterns and road network patterns help identify this land cover type. Always associated with agricultural land use. Refined through manual delineation of imagery.
1.21 Croplands (vegetated and active), Class #6, are non-flooded vegetated field, active or stubble. Typified be sorghum, milo, oats, cotton etc.
1.22 Agricultural Wetlands, Class #7, are flooded rice fields, active or senescent. Spectrally similar to naturally occurring wetlands.
1.23 Fallow Croplands, Class #8, plowed or exposed agricultural croplands. Spectrally similar to Bare Lands and some Developed Lands.

1.3 Grasslands, Class #9
Differs from Rangeland in Anderson *et. al.,* (1976) by excluding shrub-brush lands. Managed grasslands are maintained by human activity such as fertilization and used for grazing or for growing and harvesting hay for animal feed. Managed grasslands are spectrally similar to some cultivated lands. Prairie is naturally occurring grasses and forbs which are not fertilized, cut, tilled or planted regularly but often burned. Managed pastures refined through manual delineation of imagery.
Class 1.31 Managed pastures, Class #10, spectrally separated from croplands as having less biomass and tends to be associated within developed sites. Typically vegetated roadsides, improved bermuda pastures, fields in developed settings, etc. Often referred to as lightly vegetated sites.

Class 1.32 Prairie, Class #11, non-wet grasslands areas broken out by standard classification in undeveloped sites. Prairie is moderate to heavily vegetated (herbaceous) non-cropland sites and is distinguished from wetlands due to restricted hydrology. Prairie sites are often the drier sites within Coastal Prairie or Salt Prairie associations and used as rangeland.

1.4 Woody Lands, Class #12
Includes non-agricultural trees and shrubs. The category alleviates the problem of separating various sizes of trees and shrubs using satellite remote sensor data. The three classes are distinguished by spectral values.
1.41 Deciduous (non-coniferous), Class #13 dominated (>70%) by upland broad leaf woody vegetation such as *Ulmus crassifolia, Celtus laevigata, Quarcus alba, Quarcus virginiana* (while not deciduous is included), etc.
1.42 Evergreen (coniferous), Class #14 predominantly (>70%) one or more of four pine species *Pinus teada, P. elliotti, P. palustris* and *P. echniata* in the southeast.
1.43 Mixed, Class #15 Mixed associations exhibiting spectral values between the deciduous and evergreen classes.

1.5 Bare Lands, Class #16
Composed of bare soil, sand, silt, gravel. Defined by the absence of vegetation without regard to inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the vegetated classes. Bare land due to agricultural practices are classed as Cultivated Lands. Wet, non vegetated lands not created by spoil depositions are classes as Wetlands.
1.51 Unvegetated non-saline lands, Class #17, are often associated within urban settings.
1.52 Levees and Spoil Depositions, Class #18, are Bare Lands found within spoil compartments.

2.0 Wetlands Class #19
Wetlands are lands where saturation with water is the dominant factor determining soil development and the types of plant and animal communities living in the soil and on its surface (Cowardin *et al.*, 1979). A characteristic feature shared by all wetlands is the soil or substrate that is at least periodically saturated with or covered by water. The upland limit of wetlands is designated as 1) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover; 2) the boundary between soil that is predominantly hydric and soil that is predominantly non-hydric; or 3) in the case of wetlands without vegetation or soil, the boundary between land that is flooded or saturated at some time during the growing season each year and land that is not (Cowardin *et al.*, 1979). The majority of all wetlands are vegetated and are found on soil.
2.2 Marine/Estuarine Unconsolidated Shore, Class #21 unvegetated flats in the estuarine zone.
2.22 Sand (Salt and Sand flats), Class #23 High reflectance flats. Flats are largely unvegetated with occurrences of plants such as *Monanthocloe littoralis.*
2.23 Mud/organic Flats Class #24 unvegetated mud flats.

2.3 Estuarine Emergent Wetland, Class #26 herbaceous emergent estuarine wetlands both tidal and non-tidal. Hydrology a function of tides, rainfall and marsh management practices. The same vegetation species can be found in all classes of estuarine marsh, but differ in overall composition and dominants.
2.31 Haline Marsh (Salt Marsh), Class #27 is estuarine marsh with an average salinity exceeding 18 ppt.
2.311 Low Salt Marsh, Class #28 permanently flooded, tidally influenced salt marsh dominated by *Spartina alterniflora.*
2.312 High Salt Marsh, Class #29 marsh not normally tidally inundated and within the saline zone. Commonly occurring species in the upper tidal zone include *Salicornia virginica, Batis maritima,* and *Distichlis spicta.*
2.32 Mixohaline (Brackish Marsh), Class #30, is estuarine marsh with an average salinity ranging from 4 ppt - 15 ppt. Brackish Marsh species composition varies considerably from west Galveston Bay to Sabine Lake.
2.321 Low Brackish Marsh, Class #31, is flooded marsh (can be tidally flooded) dominated by *Juncus roemerianus, Distichlis spicta, Spartina patens, Scirpus maritimus.*
2.321 High Brackish Marsh, Class #32, is marsh not inundated and within the brackish zone. Species include *Spartina patens, Juncus roemerianus, Spartina spartinea, Borrichia frutescens.*
2.33 Oligohaline (Intermediate Marsh) Class #33, is estuarine marsh which can be dominated by saline or fresh water species depending on previous hydrologic conditions of site. Average salinity ranges from .5 ppt - 4 ppt. This type of marsh can be the primary wetland type from Trinity river and east Galveston Bay to Louisiana.
2.321 Low Intermediate Marsh, Class #34, is flooded marsh (can be tidally flooded) dominated by *Spartina patens, Alternanthera philoxeroids, Eleochris spp., Scripus olneyi,* and *Scirpus americanus, Phragmites australis, Scirpus californicus, Zizaniopsis miliacea.*

2.322 High Intermediate Marsh, Class #35 is marsh not inundated and within the intermediate zone. Dominant species include *Spartina patens, Spartina Spartinea, Aster spp., Paspalum vaginatum..*
2.343 Salt Prairie, Class #36, are infrequently inundated sites dominated by *Spartina spartinea, Fimberstylus* spp., and *Spartina patens*.. Salt Prairie sites are normally bounded by Saline Marsh to Brackish Marsh and Coastal Prairie or Uplands.

2.4 Estuarine Shrub-Scrub, Class #37, Seasonally and tidally flooded shrub-scrub wetlands.
2.41 Deciduous, Class #38, seasonally flooded and occasionally tidally flooded shrub-scrub wetlands dominated by *Iva frutescens* and *Baccharis grandufolia.* Dense herbaceous vegetation such as *Phragmites australis,* and *Scirpus californicus* are spectrally similar to woody vegetation and occasionally included in this class.
2.42 Evergreen, Class #39, Frequently flooded woody vegetation mostly associated with *Avicennia germinas.*
2.43 Mixed, Class #40, mostly deciduous shrubs.

2.7 Palustrine Unconsolidated Shore (Beach, Flat, Bar), Class #49, unvegetated flats in the Palustrine zone.
2.72 Sand (Salt and Sand flats), Class #51, High reflectance flats. Flats are largely unvegetated with occurrences of seasonal vegetation.
2.73 Mud/organic Flats, Class #52, mud flats with occurrences of seasonal vegetation. Vegetation when present is non-persistent and often not detected in the fall when most imagery is captured.
2.8 Palustrine Emergent Wetland, Class #53, herbaceous persistent emergent wetlands (fresh marsh). Salinity ranges between 0 ppt and 0.5 ppt. Hydrology a function of rainfall, episodic flooding and marsh management practices. The same plant species can be found in all classes of Palustrine marsh, but differ in overall composition and dominants.
2.81 Permanent, Class #54 Permanently flooded marsh dominated by obligate wetland and aquatic vegetation. Permanent wetlands are the most diverse wetlands.
2.82 Wet Prairie, Class #55 are infrequently/seasonally inundated sites characterized by mixed associations of wetland and upland vegetation on hydric soil. Hydrology is primarily a function of rainfall. Wet Prairie is spectrally similar to Salt Prairie and often grades into Estuarine Wetlands or Prairie Uplands.

2.9 Palustrine Woody Wetland (Shrub-Scrub/Forested), Class #56, woody freshwater wetlands dominated by facultative to obligate wetland woody vegetation.
2.91 Bottomland/Riparian Woodland, Class #57 Woody wetlands situated along rivers, drainages and creeks. Hydrology as function of episodic flooding and general influence of permanent riparian water source. Common species include, *Carya illinoensis, Fraxinus pennsylvanica, Taxodium distichum, Quarcus aquatica, Salix nigra, Liquidamber styraciflua* etc.
2.92 Swamps Cypress-Tupelo, Class #58, frequently flooded woodlands (Swamps) dominated by *Taxodium distichum, Nyssa aquatica* etc.
2.93 Deciduous Shrub-Scrub (Tallow-Baccharis), Class #59, wet woodlands often found on coastal prairie, spoil and former agricultural sites. On the upper Texas coast these sites are dominated by *Sapium sabiferum, Baccahris grandufolia,* and dense herbaceous stands of vegetation which can be spectrally similar to woody vegetation. Herbaceous vegetation that can be included in this class include *Typha* spp., *Arundo* spp. and *Phragmites australis.*

3.0 WATER AND SUBMERGED LAND, Class #60

3.1 Water (Bottoms and undetectable reefs, aquatic beds or nonpersistent emergent wetlands), Class #61, open water
3.10 Shallow Water, Class #82, shallow water spectrally separated. This class, depending on tidal regime is strongly correlated with mud flats and sand flats.

3.2 Marine/Estuarine Aquatic Bed, Class #69, submerged aquatic vegetation.
3.32 Rooted Vascular (e.g. seagrass), Class #70, submerged seagrass but can include *Rupia* sp., and *Vallisnaria* sp.
3.321 Dense Beds, Class, #71, solid SAV meadows.
3.322 Sparse Beds. Class #72, intermittent and clumped grass beds.

Appendix C

Sample Locations for Galveston Bay NEP Monitoring 1995-1998

YEAR = 1

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
1	95GB034	248	29	8.8479	95	5.7916
2	95GB033	267	29	9.2862	95	8.9850
3	95GB032	230	29	14.9545	95	0.0174
4	95GB031	231	29	15.0985	94	57.5400
5	95GB030	192	29	19.0006	94	52.3352
6	95GB029	194	29	20.6618	94	45.2893
7	95GB028	193	29	21.4870	94	48.0890
8	95GB027	173	29	23.9746	94	47.4655
9	95GB026	172	29	24.8141	94	52.3801
10	95GB025	171	29	26.9258	94	54.8094
11	95GB024	154	29	27.4358	94	42.4297
12	95GB023	151	29	28.2514	94	56.3255
13	95GB022	156	29	28.4116	94	37.7737
14	95GB021	152	29	29.0966	94	50.7610
15	95GB020	153	29	29.2501	94	49.9598
16	95GB019	155	29	29.5606	94	38.4883
17	95GB018	132	29	30.3162	94	52.6826
18	95GB017	136	29	30.4966	94	36.6161
19	95GB016	131	29	31.6406	94	55.9328
20	95GB015	133	29	31.8360	94	49.1249
21	95GB013	135	29	32.7776	94	38.6668
22	95GB014	129	29	32.7827	95	0.9050
23	95GB012	110	29	34.4741	94	57.5418
24	95GB011	112	29	35.8838	94	50.2542
25	95GB010	113	29	36.0045	94	46.2218
26	95GB009	111	29	37.1051	94	54.8639
27	95GB008	92	29	37.9396	94	49.2375
28	95GB007	94	29	39.0510	94	43.0829
29	95GB006	90	29	39.7697	94	59.3747
30	95GB004	74	29	40.8682	94	43.5562
31	95GB005	93	29	41.0069	94	47.9855
32	95GB002	73	29	44.0336	94	46.0853
33	95GB003	72	29	44.0876	94	50.0368
34	95GB001	54	29	45.1915	94	44.0529

YEAR = 2

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
35	96GB036	287	29	4.1029	95	11.3837
36	96GB035	267	29	6.7340	95	8.9974
37	96GB034	248	29	9.4502	95	7.3114
38	96GB033	249	29	11.9978	95	2.3030
39	96GB032	251	29	12.8033	94	56.9856
40	96GB031	192	29	20.1031	94	50.1361
41	96GB030	194	29	21.4055	94	44.9460
42	96GB029	193	29	23.2816	94	48.0748
43	96GB028	172	29	24.9549	94	49.9704
44	96GB027	175	29	26.1134	94	42.5560
45	96GB026	173	29	26.2742	94	46.0432
46	96GB024	154	29	27.6717	94	45.3484
47	96GB025	152	29	27.7715	94	51.5044
48	96GB023	153	29	27.8011	94	46.7917
49	96GB022	155	29	29.1696	94	38.7245
50	96GB020	134	29	29.7796	94	42.9565
51	96GB021	132	29	30.0515	94	52.0972
52	96GB019	136	29	30.6413	94	35.9189
53	96GB018	130	29	31.4204	94	59.3299
54	96GB016	137	29	32.1578	94	32.3717
55	96GB017	133	29	32.5659	94	48.7505
56	96GB015	131	29	33.3985	94	54.2706
57	96GB014	112	29	35.7704	94	52.8374
58	96GB013	110	29	37.0188	94	59.2781
59	96GB012	109	29	37.1013	94	59.7926
60	96GB011	92	29	37.1066	94	51.6458
61	96GB010	113	29	37.2101	94	48.4506
62	96GB009	90	29	38.3626	95	0.1753
63	96GB008	111	29	38.4949	94	53.4778
64	96GB007	94	29	38.8912	94	42.8705
65	96GB006	93	29	40.2859	94	48.2854
66	96GB005	72	29	41.5725	94	49.3621
67	96GB004	74	29	43.0508	94	43.0678
68	96GB003	73	29	43.4447	94	47.8967
69	96GB002	69	29	43.9352	95	3.0949
70	96GB001	54	29	45.8448	94	43.7526

YEAR = 3

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
71	97GB035	268	29	5.4836	95	7.5439
72	97GB034	248	29	9.9765	95	8.3720
73	97GB033	249	29	12.1934	95	2.0764
74	97GB032	230	29	13.5078	95	1.3971
75	97GB031	212	29	18.1444	94	53.2580
76	97GB030	192	29	21.5050	94	53.2201
77	97GB028	193	29	22.9646	94	47.2792
78	97GB029	172	29	22.9788	94	50.4772
79	97GB027	173	29	25.3559	94	48.5820
80	97GB025	154	29	27.0239	94	46.0922
81	97GB026	171	29	27.1564	94	53.9246
82	97GB024	152	29	28.1561	94	50.6355
83	97GB023	153	29	28.4216	94	47.6834
84	97GB022	155	29	30.5651	94	41.7476
85	97GB020	136	29	31.1619	94	39.0834
86	97GB021	132	29	31.4918	94	52.5636
87	97GB018	138	29	32.1761	94	29.8283
88	97GB019	130	29	32.6708	94	57.6700
89	97GB017	137	29	33.2552	94	34.6614
90	97GB016	133	29	33.7850	94	46.0204
91	97GB013	112	29	34.5812	94	52.4227
92	97GB015	131	29	34.6127	94	55.4681
93	97GB014	110	29	34.7503	94	58.7059
94	97GB012	113	29	35.5220	94	48.2011
95	97GB012	111	29	38.0006	94	55.9058
96	97GB011	93	29	38.7204	94	47.7566
97	97GB009	94	29	39.0985	94	42.7940
98	97GB010	90	29	39.3776	94	56.6043
99	97GB008	91	29	39.7687	94	56.4262
100	97GB007	92	29	39.9715	94	51.7181
101	97GB006	95	29	40.1985	94	42.1161
102	97GB005	74	29	41.9529	94	45.3795
103	97GB004	72	29	43.6991	94	50.2551
104	97GB003	73	29	44.2487	94	46.9826
105	97GB002	69	29	44.9764	95	3.7271
106	97GB001	54	29	47.2500	94	43.4011

YEAR = 4

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
107	98GB038	269	29	9.1636	95	4.1812
108	98GB037	250	29	11.0377	95	0.8158
109	98GB036	230	29	14.0902	95	0.2115
110	98GB035	192	29	18.5749	94	51.3886
111	98GB034	213	29	18.6326	94	49.2659
112	98GB033	193	29	23.6791	94	48.9139
113	98GB032	172	29	24.4825	94	50.8232
114	98GB031	174	29	25.6080	94	45.2458
115	98GB030	173	29	26.1129	94	48.2153
116	98GB029	154	29	27.7736	94	43.3127
117	98GB028	152	29	28.4173	94	51.7237
118	98GB027	153	29	28.7188	94	49.6051
119	98GB026	151	29	29.4688	94	54.4070
120	98GB025	132	29	30.4668	94	49.7909
121	98GB023	133	29	31.6445	94	48.8630
122	98GB024	130	29	31.7094	94	58.6802
123	98GB022	134	29	31.8350	94	42.2278
124	98GB021	136	29	32.3639	94	35.9866
125	98GB020	138	29	32.4836	94	30.2183
126	98GB019	131	29	33.5314	94	54.4885
127	98GB018	110	29	34.5711	94	58.8309
128	98GB017	112	29	34.8262	94	50.8493
129	98GB016	114	29	35.2982	94	45.1932
130	98GB015	109	29	36.7958	95	1.4360
131	98GB014	111	29	37.2993	94	56.0779
132	98GB012	113	29	38.4181	94	48.3092
133	98GB013	92	29	38.4271	94	50.5064
134	98GB011	94	29	39.5136	94	44.2424
135	98GB010	90	29	39.9549	94	57.1431
136	98GB009	93	29	40.1767	94	49.3295
137	98GB008	72	29	42.0808	94	48.8223
138	98GB006	74	29	42.4342	94	41.7737
139	98GB007	68	29	42.5825	95	3.3110
140	98GB005	73	29	44.9522	94	46.0341
141	98GB003	54	29	45.4433	94	45.3388
142	98GB004	69	29	45.8324	95	3.2277
143	98GB002	53	29	45.9521	94	46.7514
144	98GB001	55	29	49.2727	94	40.0763

Appendix D

Power Analysis Calculations

Power analyses are used to determine the probability of getting a significant result as the function of a set of defined test parameters. The power is a function of the unknown parameter values tested, the sample size, and the unknown residual error variance. There are two important uses of power analyses in statistical sampling design. These uses are; 1) prospective— where the analysis is used to predict the most effective sampling design; and 2) retrospective— where we use the power analysis to evaluate the effectiveness of an existing monitoring program. The Galveston Bay Regional Monitoring Program will utilize power analyses in both of the ways identified above. This discussion is intended to describe the use of Power Analysis capability in evaluating design parameters for this program.

As previously defined the power of a statistical test is the probability that an F achieves its $\alpha-$ critical value given a noncentrality parameter related to the hypothesis (SAS, 1994). The noncentrality parameter is zero when the null hypothesis is true, i.e. when the effect size is zero. The noncentrality parameter λ can be factored into three components through the power formula:

$$\lambda = \nu \delta^2 / \sigma^2$$

Where sigma (σ) is the standard error of the residual error in the model. When available the calculated root mean square error (RMSE) from the model is the best estimate for sigma (USEPA, 1987b); Delta (δ) is the raw effect size to be evaluated; and number (n) is the sample size. The power increases with λ, which means it increases with sample size n, and raw effect size δ, and decreases with error variance σ^2.

For purpose of this analysis, the Galveston Bay historical data sets created by Ward & Armstong were utilized to produce a model for estimating parameters of variance in the data sets. The parameters TOC, Ammonia-N, and Total Zinc were selected for detailed power evaluations. They were selected because: they represented a wide selection of variability in the data sets; there was extensive data available; and because they are important parameters for management concerns. Data to generate the design model was limited to data collected from 1986-1990. This should provide a more accurate estimate of the 5-year variability. A 5-year trend estimate is consistent with the stated goals of the monitoring program. Statistical analyses were run for each of the parameters above and the results are displayed as power curves in the following pages. SAS Institute JMP® Statistical Analysis software was used to complete these analyses.

The reduced data sets were input into the JMP **Fit Model** option. This command allows the construction of linear models using a number of complex effects. A **Standard Least Squares** model option was selected for these analyses. Some results of these analyses are shown in the following pages. Tables and plots generated by this program include summary statistics, parameter estimates, effect tests, and analysis table and leverage plot for the multiple regression model, and analysis tables and leverage plots for the effect parameter.

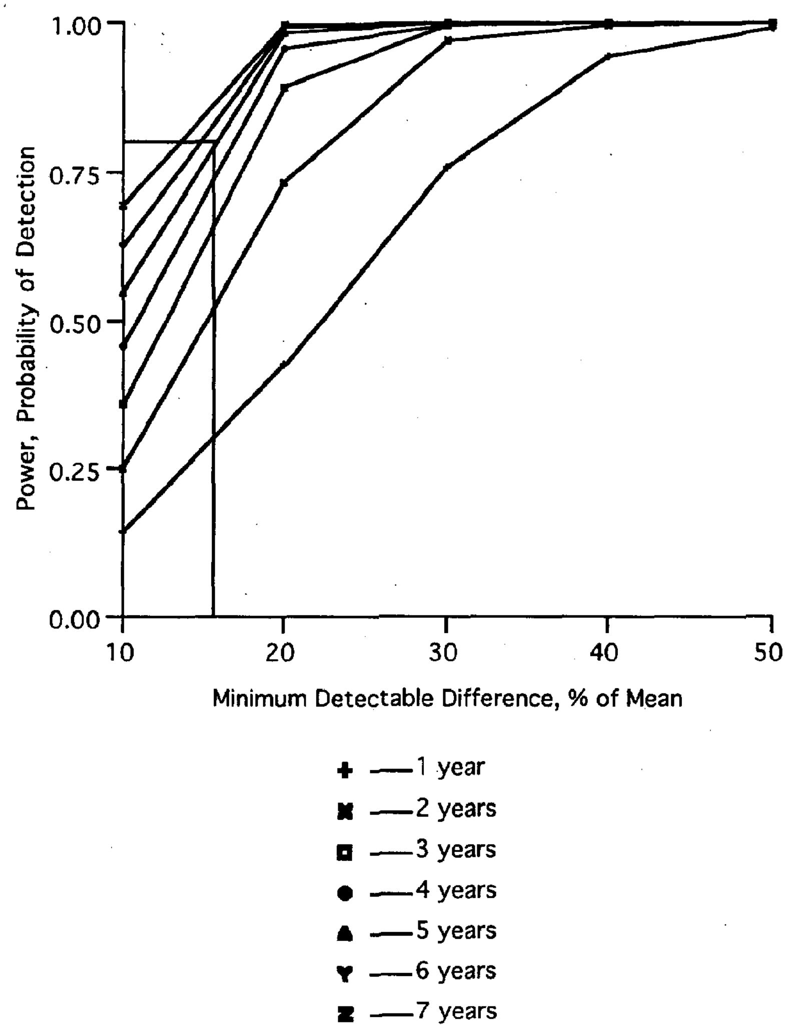
Once the model is generated the **Power Details** command for the effect parameter is selected to access the **Power Details Dialog Box**. In this dialog block, for each of the four variables alpha, n, sigma, and delta, you can fill in a single value, two values, or the start, stop, and increment for a sequence of values. The JMP® power analysis program then calculates power as a function of every combination of alpha, sample size, sigma and delta value specified. It can also calculate the LSN (least significant number) and LSV (least significant value) for each of these combinations of parameters.

A significance level of 0.05 was used for all analyses. JMP® automatically calculates the RMSE as the recommended estimate of sigma, for these analyses the estimate generated from the model was used. For sample size, n, a range from 20 to 140 at increments of 20 were used. With 5 stations per segment and four samples per year (TOC and Ammonia-N), each 20 station increment equals 1 year of sampling. For total zinc sampling will be conducted only once per year. in this example a sample size of 5 is equivalent to a year. The effect size, delta, was calculated and expressed as a percentage of the historical mean (e.g.. mean = 11.7, 10% = 1.17). This was input as a range, usually 10-50%. The results of this analysis are shown in the attached Power Details plots and tables.

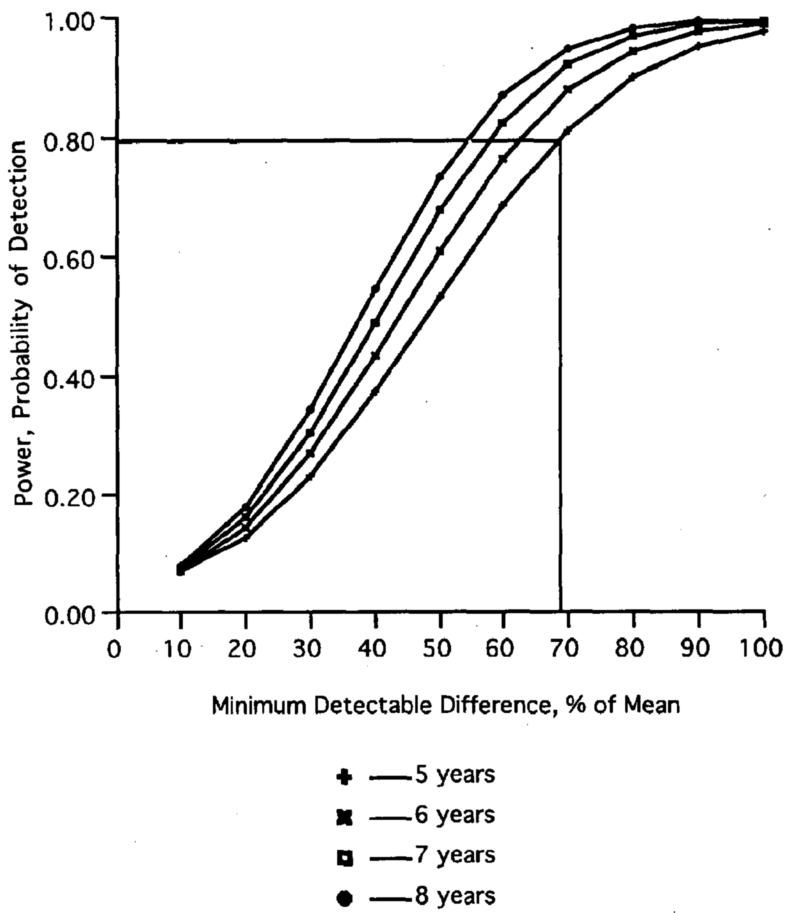
The results of these power tables can be plotted in a number of ways. The following plots express the Power of the F-test vs. the Minimum Detectable Difference that can be achieved, expressed as a percent of the sample mean. Each curve shows the response for a different number of samples, expressed as years (20 samples equals 1 year). For example, the TOC Power Plot on the following page shows that a minimum difference of approximately 16% (from the historical mean of 10.3 mg/l), or 1.65 mg/l, can be detected in the proposed 5-year sampling program. For total zinc the 5-year minimum detection is approximately 18% of the mean. Conversely, the Power Plot for Ammonia-N shows that at best the minimum detectable difference for a five year program, as defined here, would be approximately 70% of the mean.

It should be stated that the values for variance used in these evaluations will provide conservative estimates of detection levels. In calculating the estimates of variance no consideration was given to the effect of between segment or seasonal effects on variance. General estimates of variance such as standard deviation, when looked at on a segment by segment basis, show that variance may be lower or higher than the estimates used in this exercise.

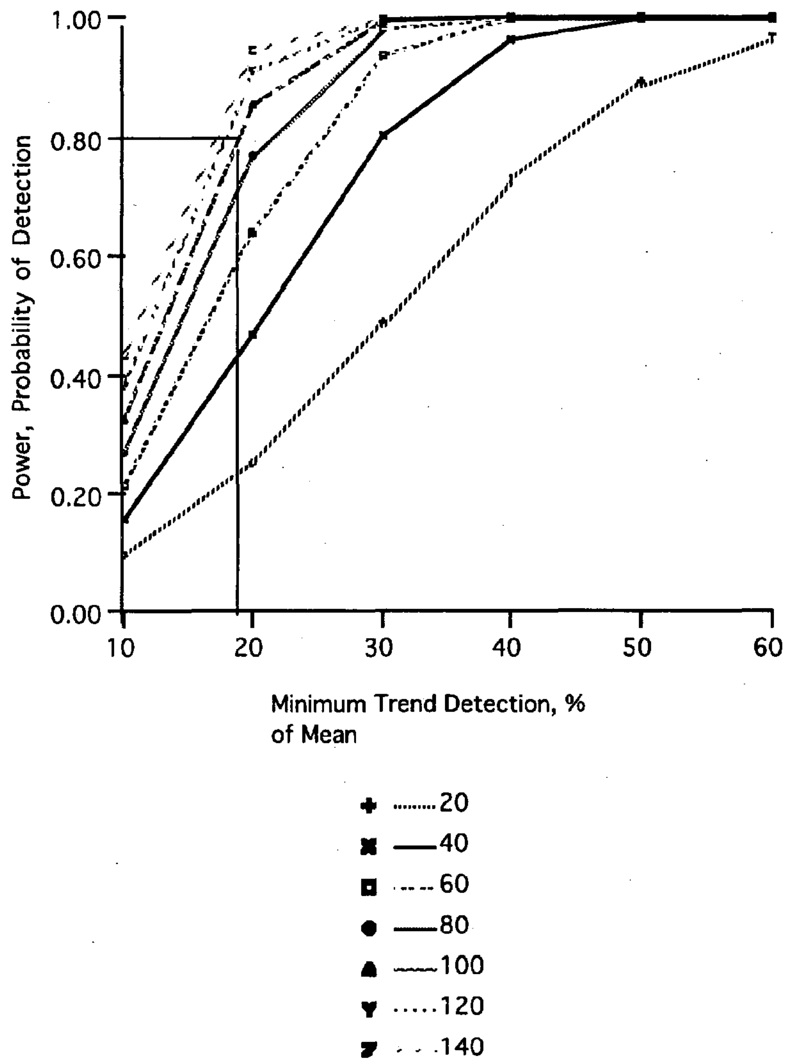
Power of the F-test vs. minimum detectable difference for TOC expressed as a percent of the mean. Design parameters alpha = 0.05, sigma = 4.9, mean = 10.3 mg/l.



Power of the F-test vs. minimum detectable difference for Ammonia-N, expressed as a percent of the mean. Design parameters: alpha = 0.05, sigma = 0.922, mean = 0.38 mg/l.



Power of the F-test vs. minimum detectable difference for total zinc, expressed as a percent of the mean. Design parameters alpha = 0.05, sigma = 24.98, mean = 37.85 mg/l.



Power Analysis Details for TOC, mg/l

Summary of Fit

RSquare	0.397099
RSquare Adj	0.396406
Root Mean Square Error	4.899137
Mean of Response	10.3138
Observations (or Sum Wgts)	872

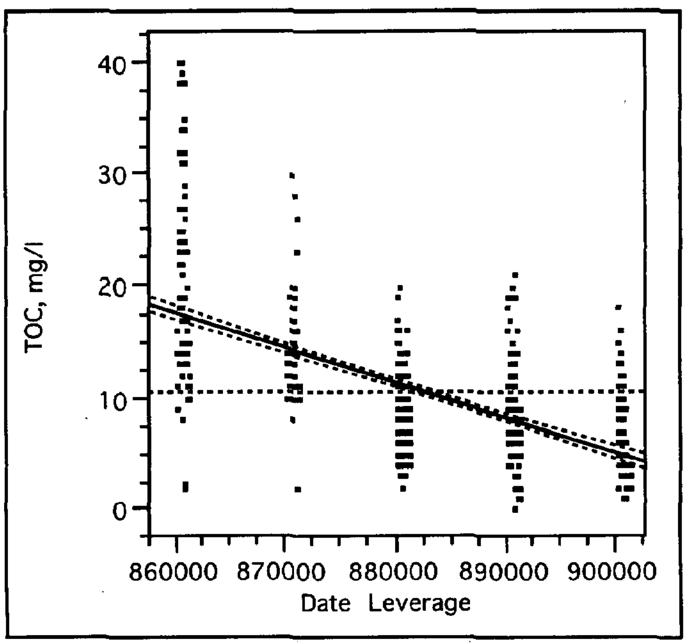
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Date	1	1	13753.462	573.0241	0.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	13753.462	13753.5	573.0241
Error	870	20881.340	24.0	**Prob>F**
C Total	871	34634.803		0.0000

Date



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
13753.462	573.0241	1	0.0000

Power Details for TOC

Test Date

Power

Alpha	Sigma	Delta	Number	Power
0.0500	4.899137	1.03	20	0.1447
0.0500	4.899137	1.03	40	0.2540
0.0500	4.899137	1.03	60	0.3602
0.0500	4.899137	1.03	80	0.4592
0.0500	4.899137	1.03	100	0.5485
0.0500	4.899137	1.03	120	0.6272
0.0500	4.899137	1.03	140	0.6951
0.0500	4.899137	2.06	20	0.4287
0.0500	4.899137	2.06	40	0.7362
0.0500	4.899137	2.06	60	0.8930
0.0500	4.899137	2.06	80	0.9603
0.0500	4.899137	2.06	100	0.9862
0.0500	4.899137	2.06	120	0.9955
0.0500	4.899137	2.06	140	0.9986
0.0500	4.899137	3.09	20	0.7604
0.0500	4.899137	3.09	40	0.9730
0.0500	4.899137	3.09	60	0.9978
0.0500	4.899137	3.09	80	0.9998
0.0500	4.899137	3.09	100	1.0000
0.0500	4.899137	3.09	120	1.0000
0.0500	4.899137	3.09	140	1.0000
0.0500	4.899137	4.12	20	0.9445
0.0500	4.899137	4.12	40	0.9994
0.0500	4.899137	4.12	60	1.0000
0.0500	4.899137	4.12	80	1.0000
0.0500	4.899137	4.12	100	1.0000
0.0500	4.899137	4.12	120	1.0000
0.0500	4.899137	4.12	140	1.0000
0.0500	4.899137	5.15	20	0.9934
0.0500	4.899137	5.15	40	1.0000
0.0500	4.899137	5.15	60	1.0000
0.0500	4.899137	5.15	80	1.0000
0.0500	4.899137	5.15	100	1.0000
0.0500	4.899137	5.15	120	1.0000
0.0500	4.899137	5.15	140	1.0000

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	4.899137	1.03	89.36652
0.0500	4.899137	2.06	24.28933
0.0500	4.899137	3.09	12.36227
0.0500	4.899137	4.12	8.283542
0.0500	4.899137	5.15	6.448558

Power Details for Ammonia-N, mg/l
Summary of Fit

RSquare	0.006138
RSquare Adj	0.005659
Root Mean Square Error	0.922698
Mean of Response	0.382256
Observations (or Sum Wgts)	2076

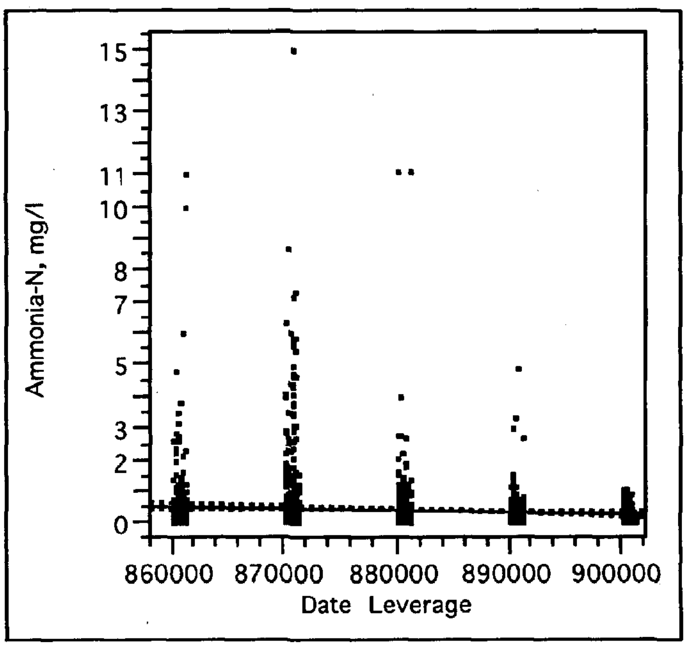
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Date	1	1	10.904908	12.8086	0.0004

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	10.9049	10.9049	12.8086
Error	2074	1765.7435	0.8514	**Prob>F**
C Total	2075	1776.6484		0.0004

Date



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
10.904908	12.8086	1	0.0004

Power Details for Ammonia-N

Test Date

Power

Alpha	Sigma	Delta	Number	Power
0.0500	0.922698	0.038	60	0.0614
0.0500	0.922698	0.038	80	0.0653
0.0500	0.922698	0.038	100	0.0693
0.0500	0.922698	0.038	120	0.0732
0.0500	0.922698	0.038	140	0.0772
0.0500	0.922698	0.038	160	0.0812
0.0500	0.922698	0.038	180	0.0853
0.0500	0.922698	0.038	200	0.0893
0.0500	0.922698	0.076	60	0.0962
0.0500	0.922698	0.076	80	0.1125
0.0500	0.922698	0.076	100	0.1290
0.0500	0.922698	0.076	120	0.1456
0.0500	0.922698	0.076	140	0.1623
0.0500	0.922698	0.076	160	0.1790
0.0500	0.922698	0.076	180	0.1958
0.0500	0.922698	0.076	200	0.2125
0.0500	0.922698	0.114	60	0.1560
0.0500	0.922698	0.114	80	0.1937
0.0500	0.922698	0.114	100	0.2314
0.0500	0.922698	0.114	120	0.2689
0.0500	0.922698	0.114	140	0.3060
0.0500	0.922698	0.114	160	0.3424
0.0500	0.922698	0.114	180	0.3779
0.0500	0.922698	0.114	200	0.4126
0.0500	0.922698	0.152	60	0.2411
0.0500	0.922698	0.152	80	0.3072
0.0500	0.922698	0.152	100	0.3713
0.0500	0.922698	0.152	120	0.4326
0.0500	0.922698	0.152	140	0.4903
0.0500	0.922698	0.152	160	0.5443
0.0500	0.922698	0.152	180	0.5942
0.0500	0.922698	0.152	200	0.6400
0.0500	0.922698	0.19	60	0.3480
0.0500	0.922698	0.19	80	0.4441
0.0500	0.922698	0.19	100	0.5315
0.0500	0.922698	0.19	120	0.6093
0.0500	0.922698	0.19	140	0.6771
0.0500	0.922698	0.19	160	0.7353
0.0500	0.922698	0.19	180	0.7846
0.0500	0.922698	0.19	200	0.8259
0.0500	0.922698	0.228	60	0.4691
0.0500	0.922698	0.228	80	0.5882
0.0500	0.922698	0.228	100	0.6868
0.0500	0.922698	0.228	120	0.7657
0.0500	0.922698	0.228	140	0.8273
0.0500	0.922698	0.228	160	0.8742
0.0500	0.922698	0.228	180	0.9094
0.0500	0.922698	0.228	200	0.9354
0.0500	0.922698	0.266	60	0.5933

0.0500	0.922698	0.266	80	0.7213
0.0500	0.922698	0.266	100	0.8145
0.0500	0.922698	0.266	120	0.8794
0.0500	0.922698	0.266	140	0.9232
0.0500	0.922698	0.266	160	0.9520
0.0500	0.922698	0.266	180	0.9704
0.0500	0.922698	0.266	200	0.9820
0.0500	0.922698	0.304	60	0.7087
0.0500	0.922698	0.304	80	0.8291
0.0500	0.922698	0.304	100	0.9036
0.0500	0.922698	0.304	120	0.9473
0.0500	0.922698	0.304	140	0.9720
0.0500	0.922698	0.304	160	0.9854
0.0500	0.922698	0.304	180	0.9926
0.0500	0.922698	0.304	200	0.9963
0.0500	0.922698	0.342	60	0.8060
0.0500	0.922698	0.342	80	0.9056
0.0500	0.922698	0.342	100	0.9564
0.0500	0.922698	0.342	120	0.9806
0.0500	0.922698	0.342	140	0.9917
0.0500	0.922698	0.342	160	0.9965
0.0500	0.922698	0.342	180	0.9986
0.0500	0.922698	0.342	200	0.9994
0.0500	0.922698	0.38	60	0.8804
0.0500	0.922698	0.38	80	0.9533
0.0500	0.922698	0.38	100	0.9829
0.0500	0.922698	0.38	120	0.9940
0.0500	0.922698	0.38	140	0.9980
0.0500	0.922698	0.38	160	0.9994
0.0500	0.922698	0.38	180	0.9998
0.0500	0.922698	0.38	200	0.9999

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	0.922698	0.038	2267.316
0.0500	0.922698	0.076	568.65
0.0500	0.922698	0.114	254.0887
0.0500	0.922698	0.152	143.9998
0.0500	0.922698	0.19	93.05255
0.0500	0.922698	0.228	65.38597
0.0500	0.922698	0.266	48.71252
0.0500	0.922698	0.304	37.8994
0.0500	0.922698	0.342	30.49442
0.0500	0.922698	0.38	25.20591

Power Details for Total Zinc, mg/l
Summary of Fit

RSquare	0.169099
RSquare Adj	0.120223
Root Mean Square Error	24.98504
Mean of Response	37.85263
Observations (or Sum Wgts)	19

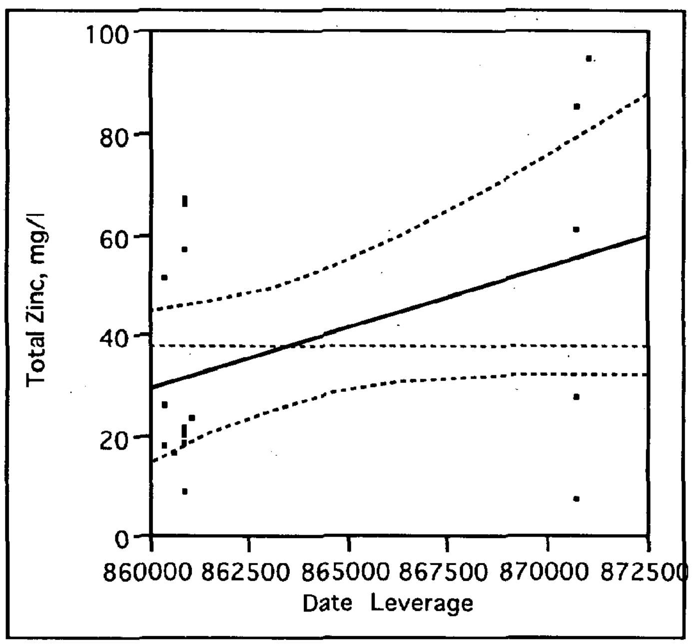
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Date	1	1	2159.7411	3.4597	0.0803

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2159.741	2159.74	3.4597
Error	17	10612.286	624.25	**Prob>F**
C Total	18	12772.027		0.0803

Date



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
2159.7411	3.4597	1	0.0803

Power Details

Test Date

Power

Alpha	Sigma	Delta	Number	Power
0.0500	24.98504	11.39	15	0.3730
0.0500	24.98504	11.39	20	0.4879
0.0500	24.98504	11.39	25	0.5885
0.0500	24.98504	11.39	30	0.6739
0.0500	24.98504	11.39	35	0.7447
0.0500	24.98504	11.39	40	0.8022
0.0500	24.98504	15.18	15	0.5861
0.0500	24.98504	15.18	20	0.7291
0.0500	24.98504	15.18	25	0.8287
0.0500	24.98504	15.18	30	0.8947
0.0500	24.98504	15.18	35	0.9367
0.0500	24.98504	15.18	40	0.9628
0.0500	24.98504	18.97	15	0.7758
0.0500	24.98504	18.97	20	0.8943
0.0500	24.98504	18.97	25	0.9529
0.0500	24.98504	18.97	30	0.9799
0.0500	24.98504	18.97	35	0.9918
0.0500	24.98504	18.97	40	0.9967
0.0500	24.98504	22.76	15	0.9028
0.0500	24.98504	22.76	20	0.9705
0.0500	24.98504	22.76	25	0.9917
0.0500	24.98504	22.76	30	0.9978
0.0500	24.98504	22.76	35	0.9995
0.0500	24.98504	22.76	40	0.9999

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	24.98504	11.39	21.06918
0.0500	24.98504	15.18	13.09589
0.0500	24.98504	18.97	9.460748
0.0500	24.98504	22.76	7.52478

Appendix E

Appendix E. Criteria Values, Used To Characterize Degraded Sediments (from Long and Morgan, 1990). NA= Not Available.

PAH (ppb)	**10% Effect Concentration** [1]	**Median Effect Concentration** [2]
Acenaphthene	150	650
Acenaphthylene	NA	NA
Anthracene	85	960
Benzo(a)anthracene	230	1600
Benzo(a)pyrene	400	2500
Benzo(b)fluoranthene	NA	NA
Benzo(e)pyrene	400	2500
Benzo(g,h,i,)perylene	NA	NA
Benzo(k)fluoranthene	NA	NA
Biphenyl	NA	NA
Chrysene	400	2800
C1, C2, C3, C4 Chrysene	400	2800
Dibenzo(a,h)anthracene	60	260
Dibenzothio	NA	NA
C1,C2, C3 -dibenzothio	NA	NA
Fluoranthene	600	3600
C1-fluoranthpyrene	NA	NA
Fluorene	35	640
C1, C2, C3 fluorene	35	640
Naphthalene	340	2100
C1, C2, C3, C4- naphthalene	340	2100
Perylene	NA	NA
Phenanthrene	225	1380
C1, C2, C3, C4-phenanthrene	225	1380
Pyrene	350	2200
1,2,3-c,d-pyrene	NA	NA
1-methylnaphthalene	NA	NA
2-methylnaphthalene	NA	NA
2,3,5- Trimethylnaphthalene	NA	NA
2,6- Dinethylnaphthalene	NA	NA
1- methylphenanthrene	NA	NA
High Molecular Wt. PAH's	NA	NA
Low Molecular Wt. PAH's	NA	NA
Total PAH's	4000	3500
PCB's (ppb)		
Total PCB's	400	NA
Individual congerners	25	NA
Pesticides (ppb)		
2,4'DDD	2.0	20
4,4'DDD	2.0	20
2,4'DDE	2.0	20
4,4'DDE	2.0	20
2,4'DDT	2.0	20
4,4'DDT	2.0	20

Appendix E. Criteria Values Used To Characterize Degraded Sediments (from Long and Morgan, 1990). NA= Not Available. (cont'd).

	10% Effect Concentration [1]	Median Effect Concentration [2]
Aldrin	NA	NA
alpha-BHC	NA	NA
beta-BHC	NA	NA
delta-BHC	NA	NA
alpha- chlordane	.5	6
gamma- chlordane	.5	6
Dieldrin	.02	8
Endrin	.02	45
Heptachlor	NA	NA
Heptachlor epoxide	NA	NA
Methoxychlor	NA	NA
Lindane	NA	NA
Toxaphene	NA	NA
Malathion	NA	AN
Parathion	NA	NA
Diazinon	NA	NA
Endosulfan	NA	NA
Mirex	NA	NA
Total BHCs	NA	NA
Metals (ppm)		
Aluminum	NA	NA
Antimony	2	25
Arsenic	33	85
Cadmium	5	9
Chromium	80	145
Copper	70	390
Iron	NA	NA
Lead	35	110
Manganese	NA	NA
Mercury	.15	1
Nickel	30	50
Selenium	NA	NA
Silver	1	2
Tin	1	3
Zinc	120	270

1 Concentration where biological effects occurred 10% of the time.

2 Median concentration for effects to occur.